Assessment of Steel End Caps with Rubber Inserts as Capping Media for Concrete Cylinders

Final Report
WVDOH RP# 136

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16. Abstract

This study was performed to find if steel end caps with removable neoprene inserts could be used as acceptable capping media for one-day old conventional concrete cylinders as well as for small concrete cylinders one day and twenty-eight days old when tested in unconfined compression.

An extensive, laboratory testing program was undertaken. Results of analyses of variance were employed in concluding that steel end caps with rubber inserts were acceptable capping media.

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EXECUTIVE SUMMARY

This study had two main objectives. One was to determine if steel end caps with removable neoprene inserts could be used as acceptable capping media when testing one day old six inch diameter by twelve inch long cylindrical specimens of conventional concrete in unconfined compression. The other was to determine if steel end caps could be used as acceptable capping media when testing small cylinders of four inches in diameter by eight inches long in unconfined compression at ages of one and 28 days old.

In this work, fifteen batches of concrete were produced, five each of three different cement factors. From each batch, twelve conventional sized cylinders and twelve small cylinders were fabricated. At an age of one day, six of each size cylinder were tested, three with steel end caps and three with the standard sulfur mortar cap. The remaining specimens were wet cured. At an age of 28 days, they were tested in the same manner as the one day old specimens.

The results of the unconfined compression tests were recorded and separated according to specimen cement factor, and age and type of capping media. An analysis of variance was then performed on the results. Using an α level of 0.05, the results of the analysis of variance were assessed to determine if the steel end caps were an acceptable alternative to the standard sulfur mortar caps for both conventional sized cylinders at age one day and for small cylinders at ages one day and 28 days.

Based on the various analyses, it was concluded that steel end caps with removable neoprene inserts can indeed serve as acceptable capping media for four inch diameter concrete cylinders that are either one or 28 days old when tested in unconfined

compression. It was also concluded that such caps can serve as acceptable capping media for one day old six inch diameter concrete cylinders tested in unconfined compression. Finally, it was recommended that WVDOH consider changing Section 601.4 of the Standard Specifications to allow the use of steel end caps when tested early age concrete cylinders in unconfined compression.

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CHAPTER ONE

INTRODUCTION

1.1. Background

The current state of practice in determining the compressive strength of concrete is to use cylindrical specimens that are six inches in diameter and twelve inches long. These specimens are bulky and heavy, each weighing approximately thirty pounds. Much space is required to store the specimens awaiting testing. Frequently, specimens are submerged in curing tanks for 28 days following their fabrication.

Another aspect of the current state of practice is to cap test specimens with a sulfur mortar compound. Specimens must be capped so that the contact surface between the testing machine and the specimen is even and planar. This ensures a uniform load distribution across the surface of the specimen. Capping is a time consuming process, not only in the actual procedure, but also in the time required for the caps to cure. Caps must cure for approximately two hours to attain sufficient strength so that they do not fail before the concrete. Such failures lead to an erroneous test result. Sulfur-based capping material liquefies at approximately 250°F. Liquefaction is required for shaping and adherence of the capping medium to the specimen. This heating produces toxic fumes; therefore, the capping area must be well ventilated. In addition, the technician performing the capping procedure is at risk for being burned.

1.2. Overview

It has been recommended by personnel at several state Divisions of Highways that a study be done to investigate the viability of using smaller specimens, four inches in diameter by eight inches long, to perform compressive strength testing. This would have many advantages over current practice. For example, the smaller specimens are much lighter, in the order of seven to ten pounds per specimen for typical weight concrete. Due to their reduced size and weight, the smaller specimens are much easier to handle and they take up much less space than the conventional larger specimens while being cured. Another advantage is that these specimens take approximately one fourth the quantity of material required by the typical specimens, which facilitates the sampling process.

Also of interest was the use of steel caps containing removable neoprene inserts as replacements for the current sulfur mortar caps. This would greatly reduce testing time because the technician would not have to wait for the caps to cure. The risk of the technician burning himself and the unpleasantness of working in the fumes released by the melting sulfur mortar material would be eliminated.

A final question was asked by state personnel. Could steel caps with neoprene inserts be used in lieu of sulfur mortar caps for compressive strength testing of both six inch by twelve inch and four inch by eight inch specimens that are one day old?

1.3. Objectives

The research study reported here had the following specific objectives:

1. To determine if steel caps with neoprene inserts can serve as an acceptable capping media for small concrete cylinders that are one or 28 days old when tested in unconfined compression.
2. To determine if steel caps with neoprene inserts can serve as an acceptable capping media for one day old conventional concrete cylinders tested in unconfined compression.

1.4. Scope

The scope of the work reported here was limited to the testing of both four inch diameter and six inch diameter specimens tested in unconfined compression. These two specimen sizes were tested using both sulfur mortar caps and steel end caps with removable neoprene inserts at two ages, one and 28 days.

Results of a previous study indicated that steel end caps with removable neoprene inserts were acceptable capping media to be used in lieu of sulfur mortar caps when conventional 28 day old concrete cylinders were tested in unconfined compression.

CHAPTER TWO

LITERATURE REVIEW

Tests to determine concrete strength have been conducted for many years. Unconfined compressive strength testing of 28 day old six inch diameter by twelve inch long specimens has been the standard technique for assessing conventional concrete for a long time (ASTM, C 31-91).[1]

2.1. Review of Past Published Literature

In 1924, Gonnerman studied the effects of uneven testing surfaces and of various methods of capping on measured compressive strength for concrete mixtures of different characteristics. For capping purposes, he used neat cement, gypsum, mixtures of gypsum and cement, beaverboard, white pine, millboard, cork and sheet rubber. He concluded that the use of the rubber sheets as a capping media caused the greatest reduction in measured compressive strength (Gonnerman, 1924).

Later, in 1925, Gonnerman performed a study on the effect of size and shape of the test specimen on measured compressive strength. He prepared a variety of specimens of different geometries. There were cylindrical specimens with height to diameter ratios of two with diameters that varied between 1½ inches to ten inches. He also used cylinders varying from three to ten inches in diameter, all twelve inches in height, and varying from three to 24 inches in height and six inches in diameter. He tested cubes of both six and eight inches and prisms six inches by twelve inches and eight inches by 16

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[1]Information in parentheses refers to references found in the reference section of this report.

inches. These various specimens were tested at ages varying from seven days to one year. Using cylinders with height to diameter ratios of two as the control group for comparison purposes, cylinders with height to diameter ratios of three and four showed a decrease in measured compressive strength from five to ten percent. Results indicated that strength continues to decrease rapidly as the height to diameter ratio increases above four (Gonnerman, 1925).

In 1942, Johnson performed another study comparing the height of test specimens to their measured compressive strength. His findings confirmed those stated earlier by Gonnerman. Johnson concluded that when testing cylindrical specimens for which the height to diameter ratio is greater than two, a correction factor should be used when comparing the measured compressive strength with that of a standard six inch by twelve inch cylinder (Johnson, 1942).

In 1951, Price studied the influence of specimen geometry on measured compressive strength of concrete cylinders. He concluded that for cylindrical specimens with a height to diameter ratio of two that specimen size does play a significant role in the measured compressive strength. Using cylinders of six inch diameter as the control group, he observed that for cylinders greater than six inches in diameter, the strength was found to decrease as the specimen size increased and for cylinders less than six inches in diameter, the strength seemed to increase as the specimen size decreased (Price, 1951).

In 1958, Werner studied the effects of capping materials on the measured compressive strength of conventional concrete cylindrical specimens. He concluded that varying the capping material does have a definite effect on the measured compressive strength (Werner, 1958).

In 1964, Newman and Lachance studied the deformation behavior of prismatic concrete specimens with varying geometries. They used specimens of four inches square ranging in height from four to twenty inches and measured the longitudinal and lateral deformations. They observed that the lateral deformation at approximately the mid-height of the specimens was greater for the smaller specimens and decreased with an increase in specimen height. This showed that tangential stresses present at the ends of the specimens decreased rapidly with increasing distance from the ends (Newman and Lachance, 1964).

In 1978, a study by Bowery and Higgins compared five different capping systems to the standard sulphur mortar capping material for use on standard six inch diameter by twelve inch high cylindrical specimens for quality assurance testing performed at 28 days. From this study, it was concluded that steel end caps with removable neoprene inserts can be used in place of the standard sulfur mortar capping material without the addition of a correction factor for apparent strength differences (Bowery and Higgins, 1978).

In 1993, Pistilli and Willems compared sulfur mortar caps to an unbonded polymer pad capping system for both four inch diameter and six inch diameter cylinders for concrete with measured 28 day compressive strengths ranging from 3000 psi to 18,000 psi. They concluded that, at the 95% confidence level, there was no significant difference between strengths obtained with the polymer pad capping system and the sulfur mortar capping system for concretes with measured unconfined compressive strength up to 8000 psi for six inch diameter specimens and up to 13,000 psi for four inch diameter specimens. They also concluded that within-test variances shown by six inch diameter specimens were similar to the variances shown by the four inch diameter specimens (Pistilli and Wilems, 1993).

In 1994, Day performed an analysis of data published in twenty publications ranging from 1925 to 1994. He compared measured compressive strengths of six inch, four inch and three inch diameter cylinders. Day concluded that the coefficient of variation of measured compressive strength for four inch diameter cylinders was not significantly different from the coefficient of variation of the measured compressive strength of six inch diameter cylinders. He also concluded that if the cylinders are cast using plastic or steel molds and the measured compressive strength was in the range of 3000 psi to 14000 psi, the measured compressive strengths of four inch diameter cylinders was approximately five percent higher than that of six inch diameter cylinders (Day, 1994).

2.2. Summary of Literature Review

The following statements can be made based on a review of the available literature.

1) When using various capping media, the use of rubber sheets causes the greatest reductions of compressive strengths.
2) Strength of cylindrical specimens decreases as length to diameter ratio increases over two and decreases rapidly as this ration exceeds four.
3) A correction factor should be employed when comparing compressive strength of cylindrical test specimens with a length to diameter ratio greater than two to strengths measured using six inch diameter by twelve inch long specimens.

4) For cylindrical test specimens with a length to diameter ratio of two, as the diameter increases above six inches the compressive strength decreases and as the specimen diameter decreases, the compressive strength increases.
5) Variations in capping media have definite effects on compressive strength.
6) Tangential stresses present at the ends of specimens decrease rapidly with increasing distance from the ends.
7) Steel end caps with neoprene inserts can be used when testing 28 day old cylindrical specimens in unconfined compression without employing a correction factor.
8) There is no significant difference between compressive strengths for specimens tested with polymer pad capping systems and sulfur mortar caps for strengths up to 8000 psi for six inch diameter specimens and up to 13,000 psi for four inch diameter specimens.
9) The measured compressive strength of four inch diameter cylinders is approximately five percent higher than that of six inch diameter cylinders when the strengths are between 3000 and 14,000 psi.

CHAPTER THREE

LABORATORY INVESTIGATION

3.1. Designed Experiment

The designed experiment for this study included the fabrication of both six inch diameter by twelve inch high cylindrical concrete specimens and four inch diameter by eight inch high cylindrical specimens to be tested in unconfined compression at both one and 28 days. Specimens were tested using both sulfur mortar capping material and steel end caps with neoprene inserts, with three replications of each test (size and capping system variations). The experiment required that fifteen batches of concrete be produced, each of sufficient volume to fabricate twelve six inch by twelve inch specimens, twelve four inch by eight inch specimens and also enough concrete to perform slump and air content tests. This required approximately four cubic feet of concrete. To ensure that all batches were as close to identical as possible with the exception of a planned difference in cement contents, one coarse aggregate, one fine aggregate and the same brand of cement were used in the preparation of all specimens. Mix designs were typical of concrete mixes specified by the West Virginia Division of Highways for the three cement contents (5, 6, and 7.25 bags/CY) being tested. Mixture water-cement ratios appear below in Table 3.2. They were obtained using Table 601.3.1 of the West Virginia Standard Specifications for Roads and Bridges, 1994.

A total of 15 batches of concrete were prepared. To ensure randomness, a random number generator was used to obtain the assignment of batches to the different cement contents. The sample preparation plan is given in Table 3.1.

Table 3.1. Cement Factors and Corresponding Batch Number

Cement Content (Bags/Cubic Yard)	Batch Numbers
5	4, 5, 12, 14, 15
6	1, 6, 8, 9, 11
7.25	2, 3, 7, 10, 13

3.2. Proportions and Materials

3.2.1. Mixture Proportions

The general mix design proportions for the concrete mixtures used in this study are shown in Table 3.2. The proportions for each individual batch can be found in Table A.4 in Appendix A.

Table 3.2. Proportions for Laboratory Mixes (Pounds / CY)

Material	Cement Factor (Bags / CY)		
	5.00	6.00	7.25
Cement	470	564	682
Coarse Aggregate	1850	1805	1625
Fine Aggregate	1140	1110	995
Water	275	250	341
Maximum Water-Cement Ratio	0.58	0.44	0.50
Air Content (%)	7	7	7

3.2.2. Concrete Materials

The coarse aggregate used was a crushed limestone that corresponded to a #57 gradation (ASTM C 33, 1995). Results of the coarse aggregate gradation tests appear in Table A.1 and Figure A.1 in Appendix A. The fine aggregate used was a washed Ohio River sand that had an average $\bar{A}$ of 6.32 for normal gradations and an average $\bar{A}$ of 6.41 for a washed gradation. $\bar{A}$ is a measure of relative coarseness of a fine aggregate used in the production of concrete. Results of the gradation tests for the fine aggregate appear in Tables A.2 and A.3 and Figures A.2 and A.3. The calculation procedure for $\bar{A}$ can be seen in Appendix A. The cement used was manufactured by Armstrong and was classified as a Type I cement by the procedure outlined in ASTM C 150-95 (ASTM, 1995).

3.3 Mixing and Specimen Fabrication

To mix the concrete batches, all of the dry ingredients (the cement, fine and coarse aggregate) were weighed and added to the hopper of a pan mixer in the concrete laboratory. Next, the water and air entrainment admixture were measured. The water was then separated into two buckets, one containing approximately ⅔ of the water and the other bucket containing the remaining ⅓. The air entraining admixture was added to the bucket containing ⅔ of the water to try to achieve a more even dispersion of entrained air throughout the concrete. The pan of the mixer was lightly coated with water. The pan was then charged with the dry ingredients which were allowed to mix for a short period of time before the water and air entrainment was added over the side of the pan. The water from the other bucket was added until the concrete slump was estimated to be approximately three inches. At this point, the mixing was stopped and the concrete was tested for slump, following ASTM C 143-90a, and entrained air content, according to ASTM C 231-91b (ASTM, 1995). Concrete used for these tests was then discarded.

Once the plastic concrete tests were performed, the specimens were prepared. Twelve small specimens and twelve standard size specimens were fabricated from each batch of concrete using plastic specimen molds. The cylinders were fabricated by following ASTM C 192 - 90a (ASTM, 1995).

The specimens were covered with plastic and left to cure overnight. The next morning, The specimens were removed from the mold. At this time, half of each size of the specimens were submerged in a curing tank to await 28 day testing, leaving six specimens of each size for one day testing. Three of each size specimens were then set aside to be tested with steel caps while the other three specimens were capped with the sulfur mortar material. After the sulfur caps had been cured for a sufficient amount of time, the specimens were tested.

3.4. Plastic Concrete Characteristics

The characteristics of the plastic concrete for each batch appear in Table 3.3.

Table 3.3 . Plastic Concrete Characteristics

Batch Number	Slump in Inches	Air Content in Percent
1	3¼	6.5
2	2⅝	6.2
3	3½	6.5
4	3	6.2
5	2¾	6.8
6	3½	7.0
7	3½	6.5
8	2¾	6.4
9	3	6.6
10	2⅝	6.4
11	2¾	6.3
12	2⅝	7.4
13	2⅝	6.7
14	2¾	7.0
15	2½	6.6

Averages and variability of results of the tests on the plastic concrete can be seen in Table 3.4. The concrete had an average slump of 2.92 inches with a range of one inch. The average entrained air content was 6.62% with a range of 1.2%.

Table 3.4. Statistics from the Results of Tests on Plastic Concrete

	Slump in Inches	Air Content in Percent
Average	2.92	6.61
Standard Deviation	0.34	0.32
Coefficient of Variation in Percent	11.78	4.83
Minimum	2.5	6.2
Maximum	3.5	7.4
Range	1.0	1.2

3.5. Statistical Analysis Procedures

The following statistics were calculated for each of the three cement contents at each curing time for each cylinder size and for each capping type:

1. Average Compressive Strength
2. Standard Deviation of Strength
3. Coefficient of Variation
4. Within-test Averages
5. Within-test Standard Deviation
6. Within-test Coefficient of Variation
7. Range of Strength

The results of these calculations are displayed and discussed in the Results and Discussion section of this report, Chapter Four.

Also, an analysis of variance was performed on the results of the measured compressive strength. In this analysis, the effects of capping, specimen size, curing time and cement content on the measured compressive strength of the concrete specimens were investigated. The results of the analysis of variance can be found in this report in Chapter Four, Section Two.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Compressive Strength Test Results

Data for compressive strength test results for each individual cylinder tested appear in Tables B.1 through B.12 in Appendix B.

4.1.1. One Day Old Specimens

Statistics were calculated from the unconfined compressive strength tests performed on one day old cylinders. Overall averages, standard deviations and coefficients of variation of the compressive strengths of all specimens tested at one day old appear in Table 4.1. These statistics were derived using the averages of each set of three tests.

Table 4.1. Average (psi), Standard Deviation (psi) and Coefficient of Variation (Percent) of Compressive Strength at One Day

Cement Factor		4" x 8"		6" x 12"	
		Steel/Neoprene	Sulfur Mortar	Steel/Neoprene	Sulfur Mortar
5.0	$\bar{x}$	1293	1363	1424	1515
	α	161	130	106	123
	ν	12.5	9.5	7.4	8.1
6.0	$\bar{x}$	1668	1781	1841	1915
	α	101	161	208	228
	ν	6.1	9.0	11.3	11.9
7.25	$\bar{x}$	2420	2429	2556	2542
	α	150	125	184	112
	ν	6.2	5.1	7.2	4.4

As expected, the average compressive strength (average included all specimens with the same cement content) of the specimens increases with increasing cement content. For the four inch diameter specimens prepared with five bags of cement per cubic yard, the average compressive strength for the specimens tested with steel end caps with removable neoprene inserts was 1293 psi. For those specimens tested with sulfur mortar caps, the average was 1363 psi. For batches prepared with six bags of cement per cubic yard, the average compressive strength of the specimens tested with steel end caps was 1668 psi versus 1781 psi for specimens capped with sulfur mortar. For mixes prepared with 7.25 bags of cement per cubic yard, the average compressive strength of the specimens tested with steel end caps was 2420 psi. For those specimens tested with sulfur mortar caps, the average compressive strength was 2429 psi.

For six inch diameter cylinders prepared with batches containing five bags of cement per cubic yard, the average compressive strength for the specimens tested with steel end caps was 1424 psi. For those companion specimens tested with sulfur mortar caps, the average compressive strength was 1515 psi. For batches prepared with six bags of cement per cubic yard, the average compressive strength for the specimens tested with sulfur mortar caps was 1915 psi. For those specimens tested with steel end caps, the average compressive strength was 1841 psi. For the batches prepared with 7.25 bags of cement per cubic yard, the average compressive strength of those specimens tested with steel end caps was 2556 psi versus 2542 psi for comparable specimens with sulfur mortar caps.

One trend that was consistent throughout the study was that the compressive strength was greater for the specimens tested with sulfur mortar caps than those tested utilizing steel end caps regardless of the specimen size. Figures 4.1 through 4.6 show this fact graphically using the averages of three cylinders tested from each batch for each cement content. In these figures, all factors other than size were held constant to isolate the relationship of type of capping media to compressive strength. The results clearly show that specimens tested with sulfur mortar caps had higher compressive strengths than those tested with steel end caps at one day old. Regression analyses were performed between compressive strengths obtained with sulfur mortar caps and strengths obtained using steel caps for each of the cases. Results appear below the individual Figures.

Another trend realized was that the compressive strength was greater for the conventional sized specimens than for small cylinders. Figures 4.7 through 4.12 exhibit this trend. Shown in the figures are average strengths of the three specimens tested from each batch with each capping system. As before, all factors other than specimen size were held constant to isolate the relationship between specimen size and compressive strength. The trends indicate that the compressive strength for the conventional sized cylinders was greater than that of the smaller cylinders. Regression analyses were performed between compressive strengths obtained with 6"x12" cylinders and strengths obtained with 4"x8" cylinders. Results appear below the individual figures.

Standard deviations and coefficients of variation of specimens capped with sulfur mortar were comparable to published values for one day old tests performed by Hudson and Steele in 1975 (Hudson and Steele, 1975). No comparable values were available for one day old specimens tested with steel end caps. However, the test values did tend to mirror those found using the sulfur mortar compound. Overall standard deviations tended to be constant throughout the testing sequence for the one day old specimens with the exception of six inch diameter specimens made with mixes with six bags of cement per cubic yard. Coefficients of variation tended to decrease with an increase in cement factor, again excepting six inch diameter specimens made with mixes containing six bags of cement per cubic yard of concrete.

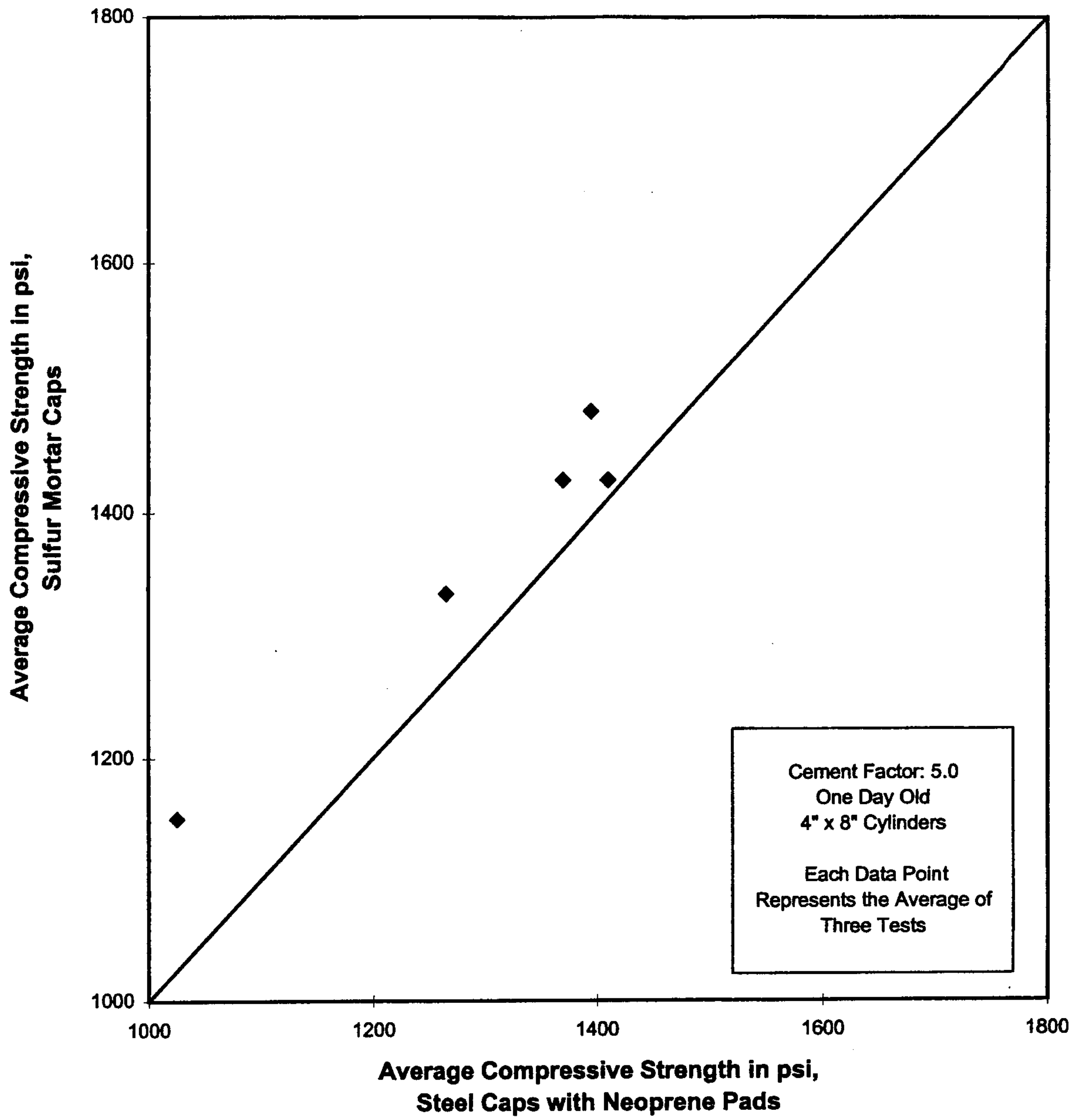

Figure 4.1. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

Regression Equation:

$$M = 337 + 0.793S$$

Where:

M = Compressive strength, in psi, using sulfur mortar caps

S = Compressive strength, psi, using steel caps

R^2 = Square of the correlation coefficient = 0.965

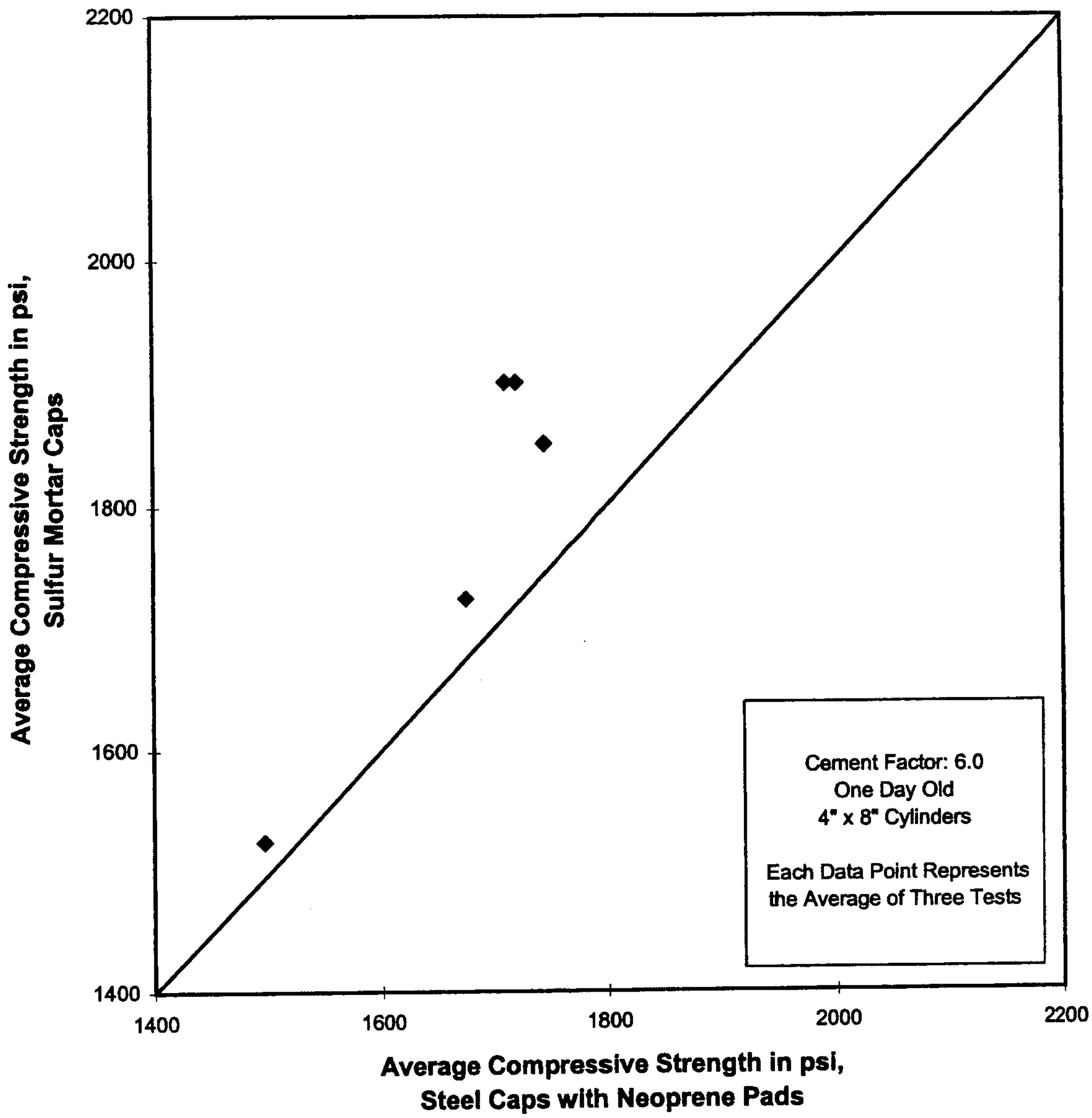

Figure 4.2. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

Regression Equation:

$$M = -721 + 1.500S$$

Where:

M = Compressive strength, in psi, using sulfur mortar caps
S = Compressive strength, psi, using steel caps
R^2 = Square of the correlation coefficient = 0.895

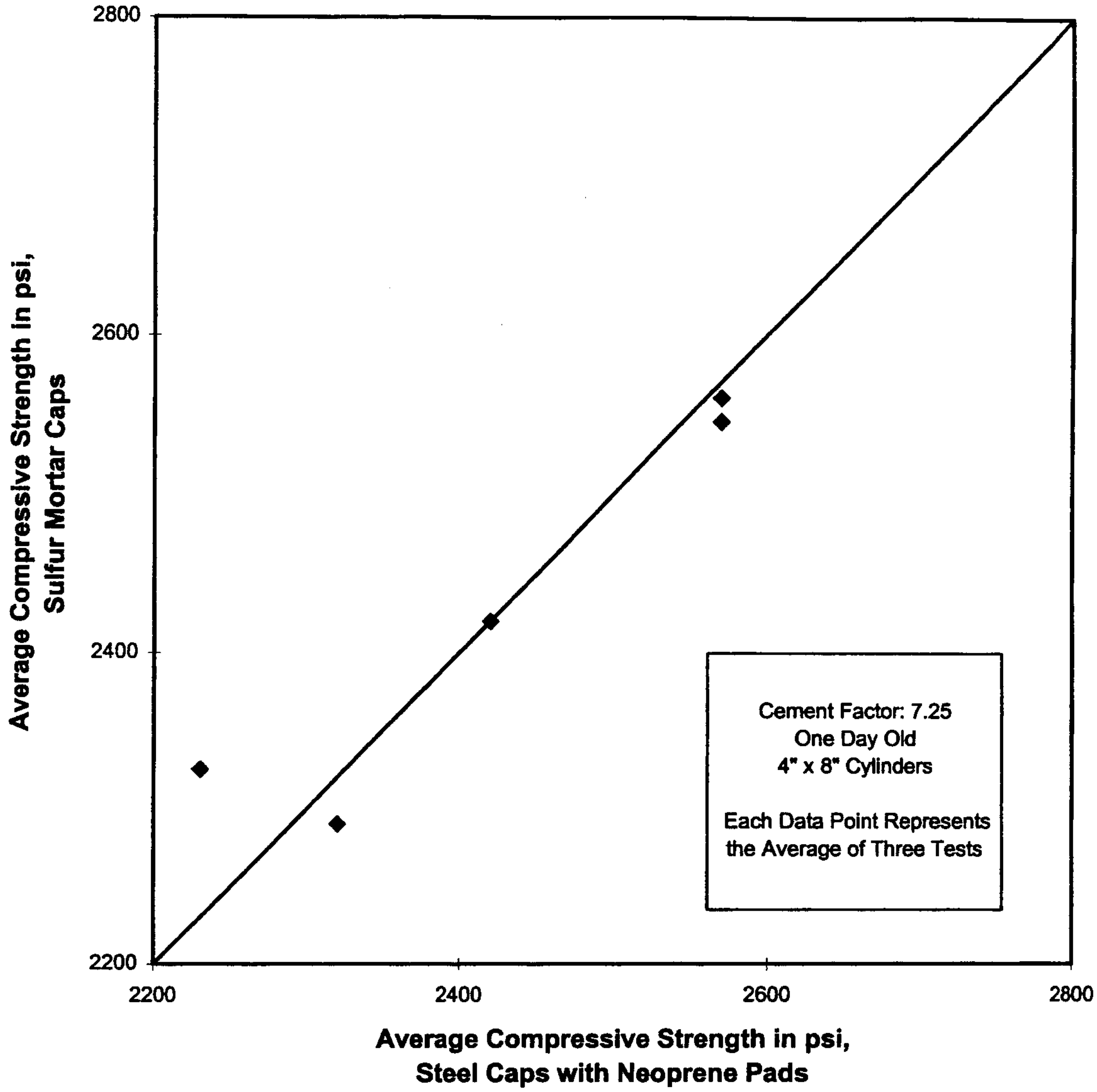

Figure 4.3. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

Regression Equation:

$$M = 513.8 + 0.791S$$

Where:

M = Compressive strength, in psi, using sulfur mortar caps
S = Compressive strength, psi, using steel caps
R^2 = Square of the correlation coefficient = 0.907

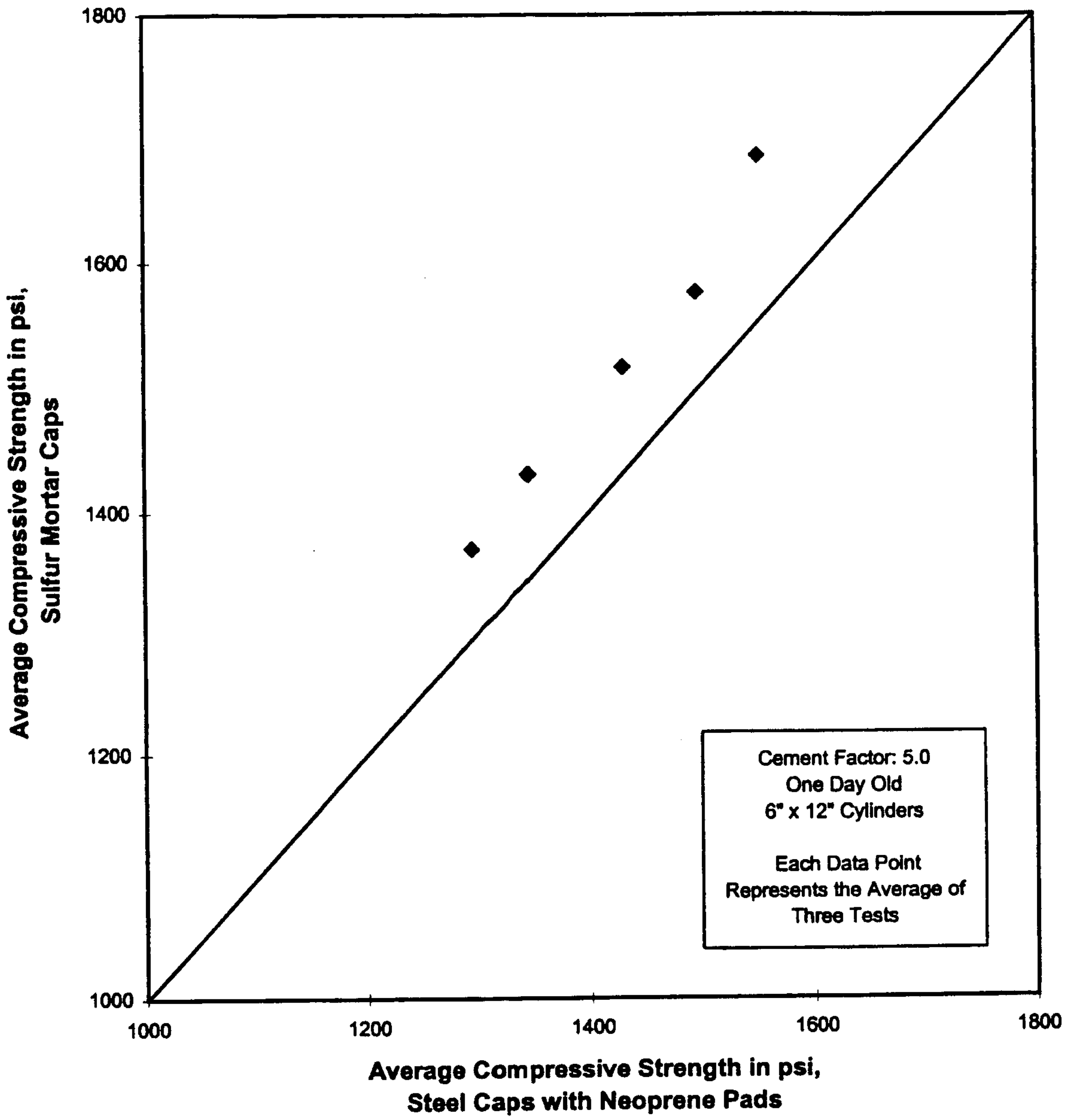

Figure 4.4. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

Regression Equation:

$$M = -122 + 1.150S$$

Where:

M = Compressive strength, in psi, using sulfur mortar caps

S = Compressive strength, psi, using steel caps

R^2 = Square of the correlation coefficient = 0.977

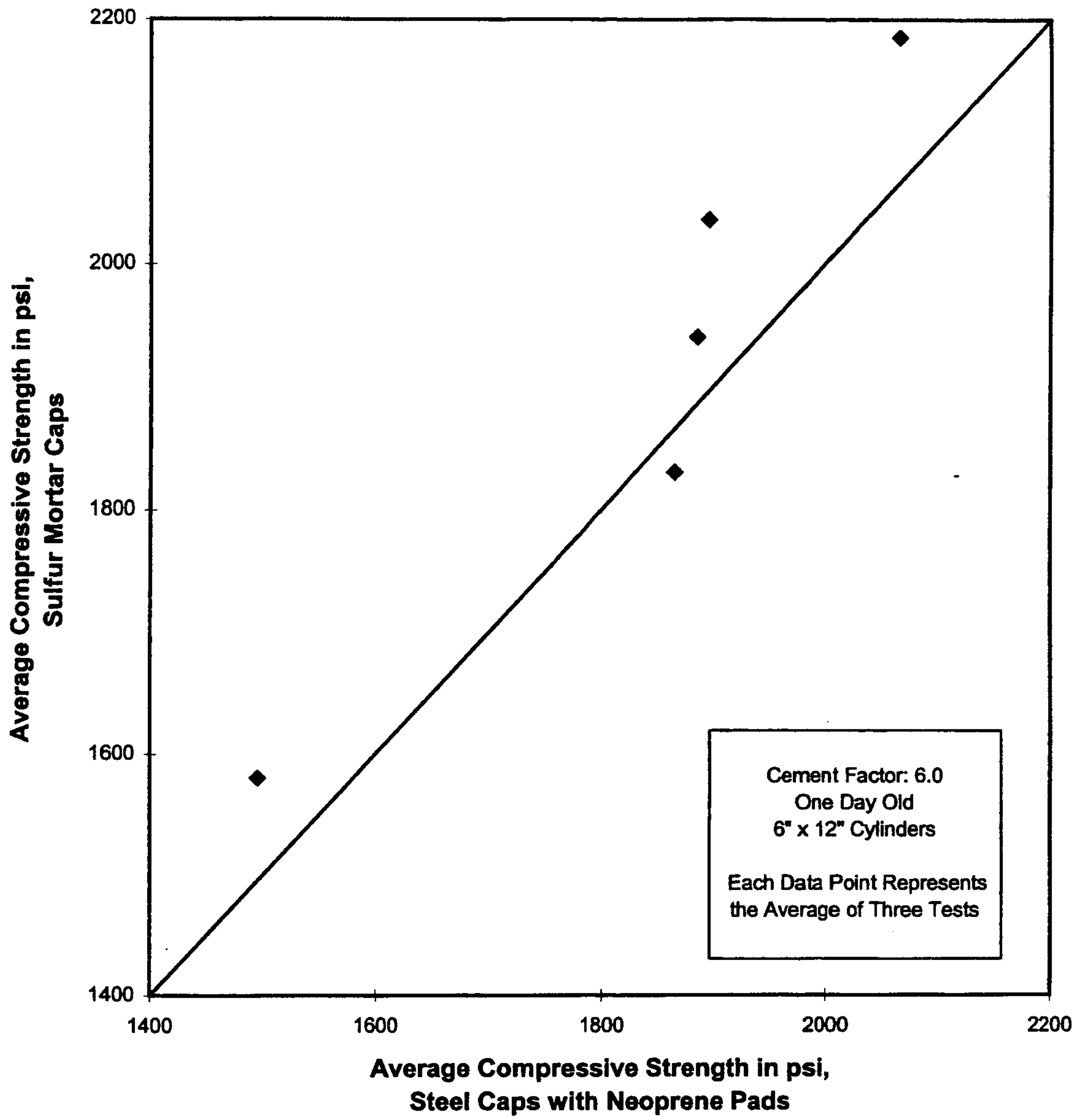

Figure 4.5. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

Regression Equation:

$$M = -13.5 + 1.048S$$

Where:

M = Compressive strength, in psi, using sulfur mortar caps

S = Compressive strength, psi, using steel caps

R^2 = Square of the correlation coefficient = 0.909

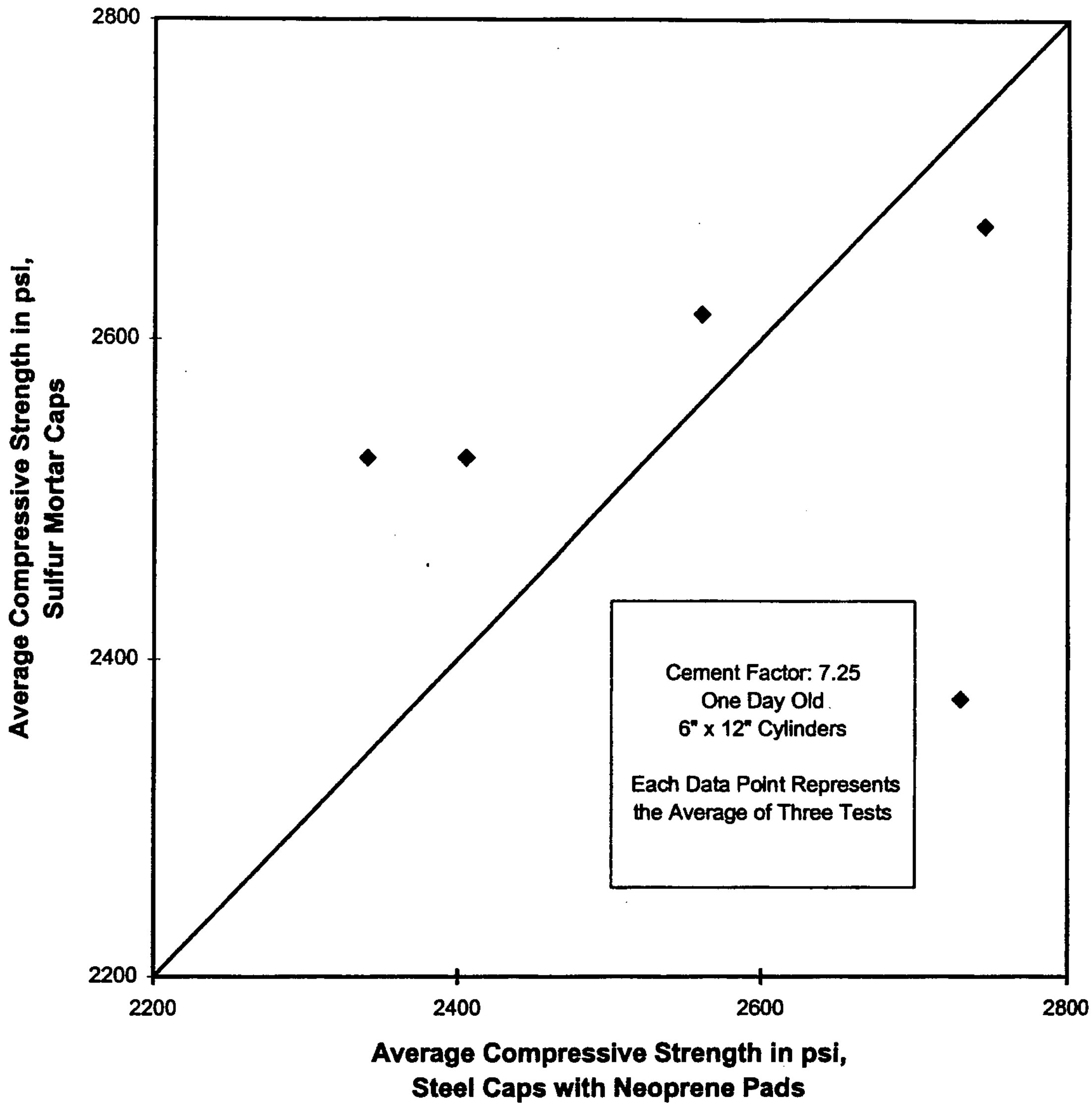

Figure 4.6. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

Regression Equation:

$$M = 2488 + 0.021S$$

Where:

M = Compressive strength, in psi, using sulfur mortar caps

S = Compressive strength, psi, using steel caps

R^2 = Square of the correlation coefficient = 0.001

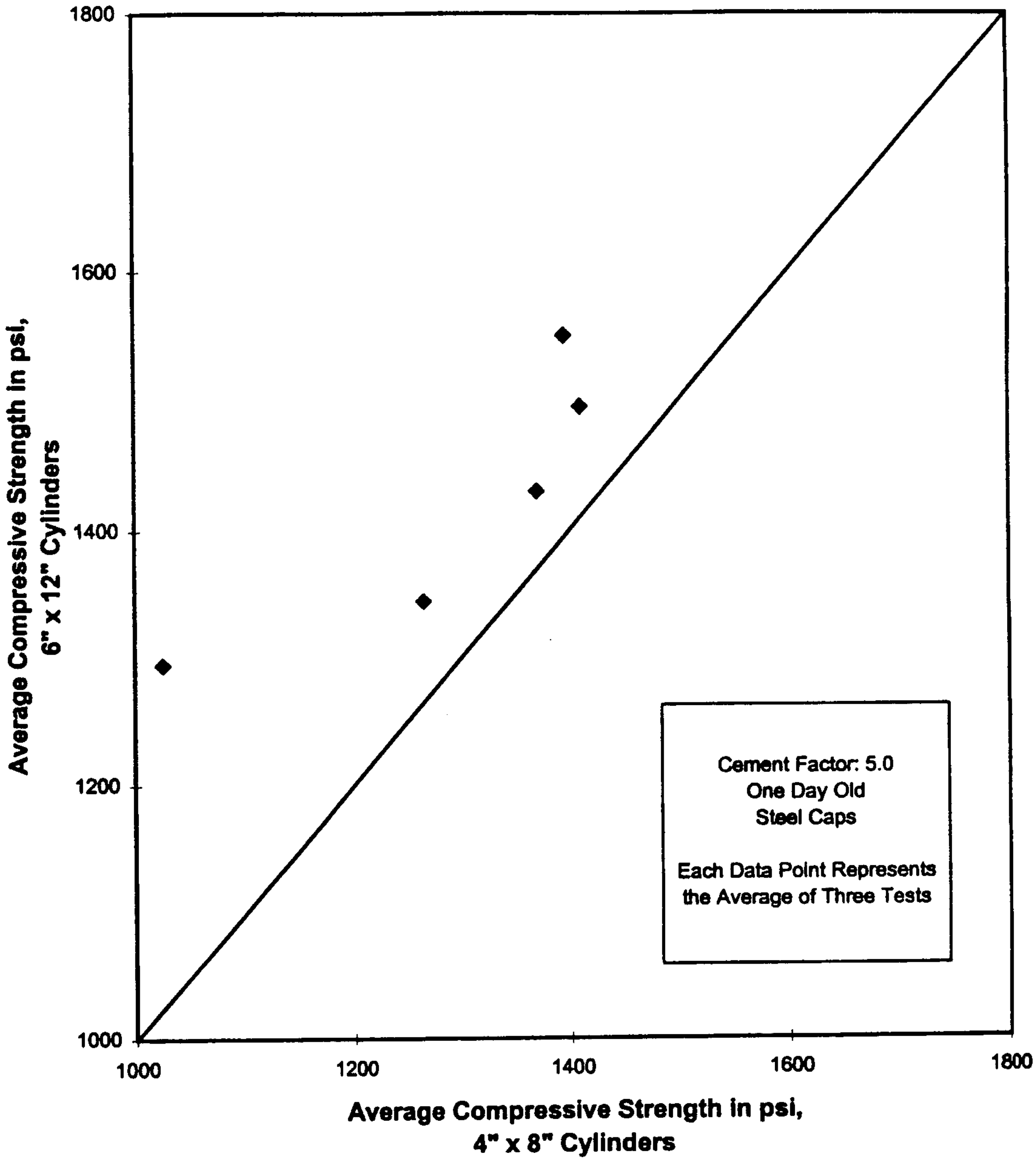

Figure 4.7. Average Compressive Strengths of Different Size Concrete Cylinders

Regression Equation:

$$Y = 685.3 + 0.571X$$

Where:

Y = Compressive strength, in psi, using 6"x12" cylinders
X = Compressive strength, psi, using 4"x8" cylinders
R^2 = Square of the correlation coefficient = 0.760

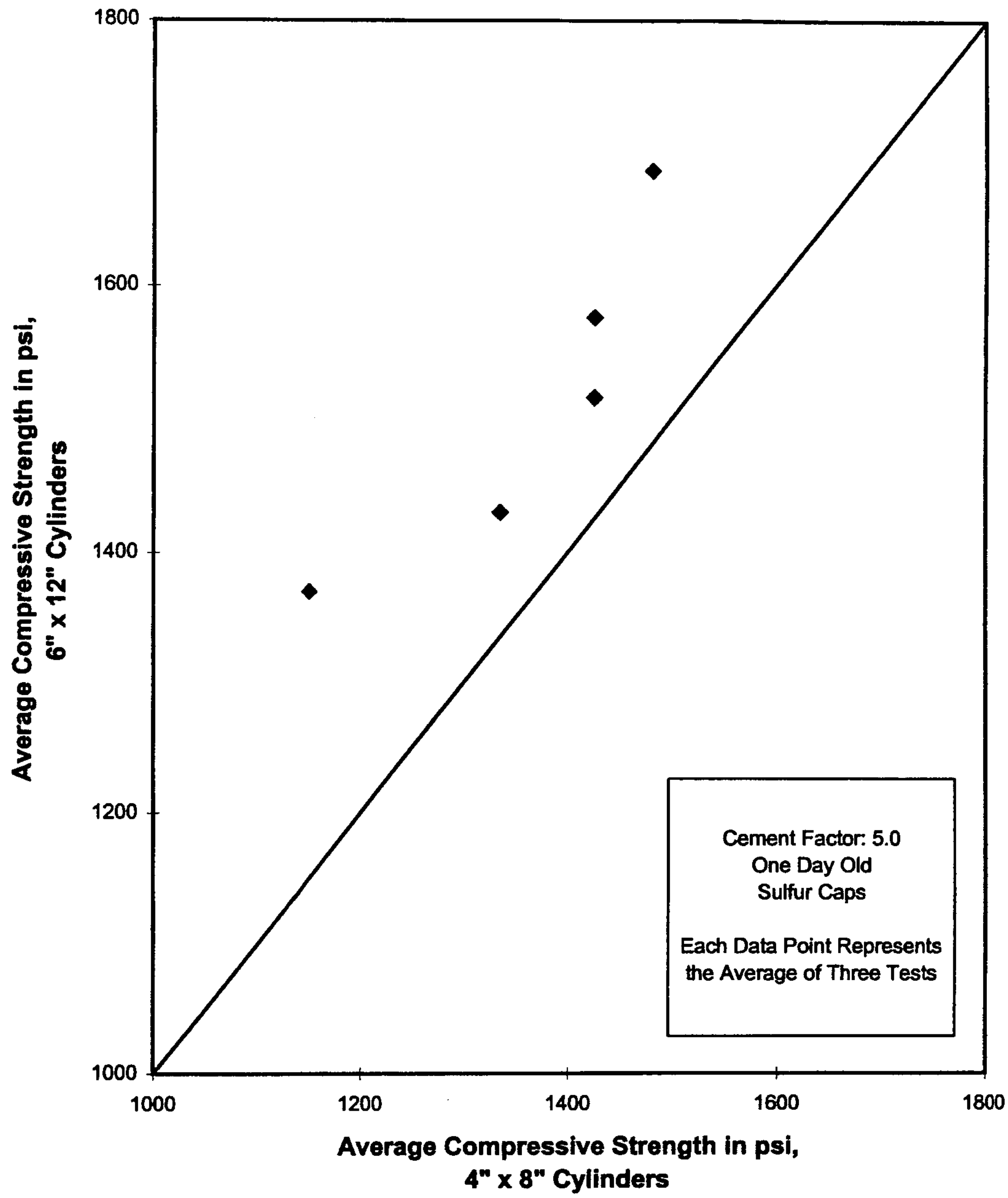

Figure 4.8. Average Compressive Strengths of Different Size Concrete Cylinders

Regression Equation:

$$Y = 374.6 + 0.837X$$

Where:

Y = Compressive strength, in psi, using 6"x12" cylinders
X = Compressive strength, psi, using 4"x8" cylinders
R^2 = Square of the correlation coefficient = 0.787

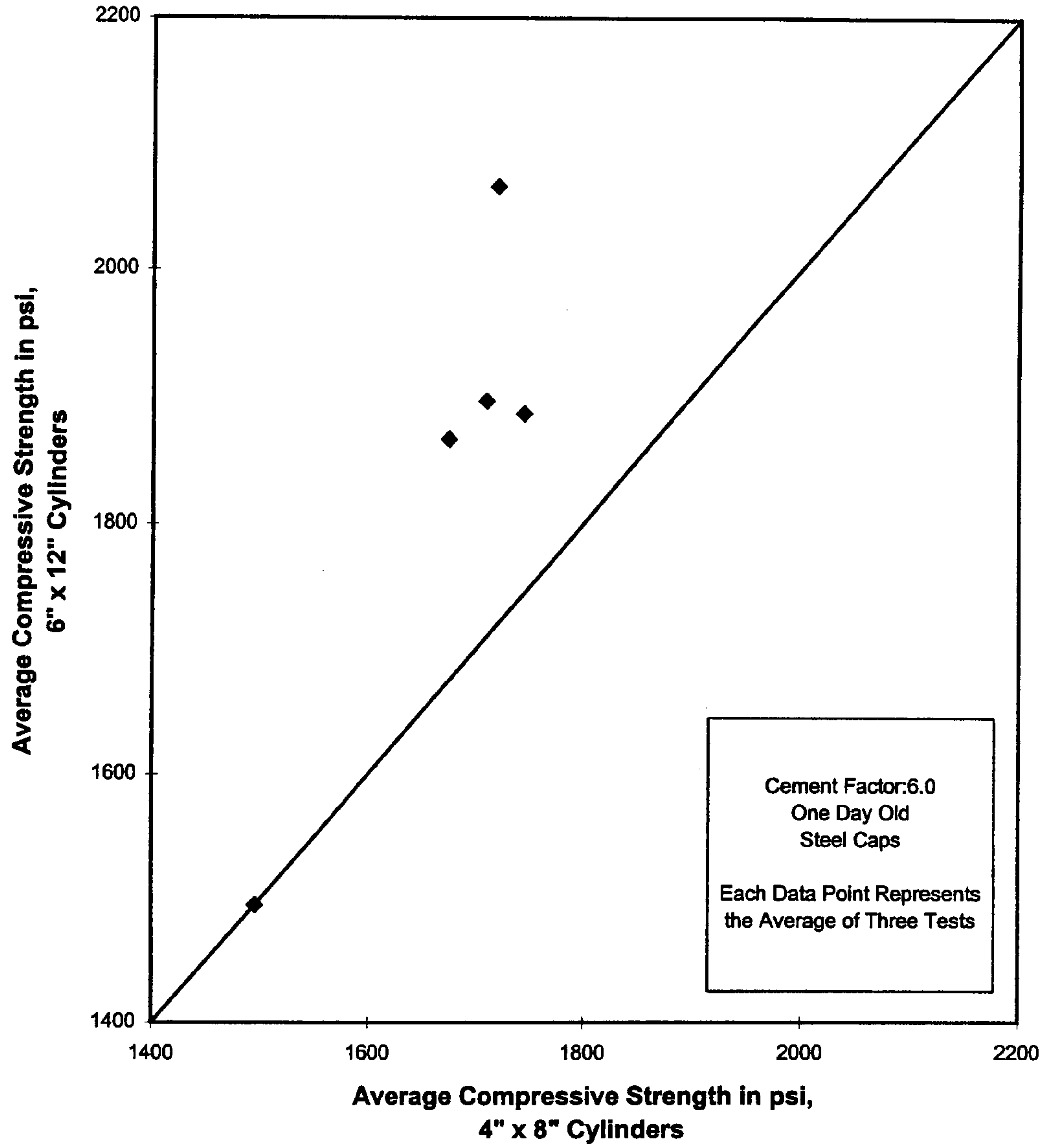

Figure 4.9. Average Compressive Strengths of Different Size Concrete Cylinders

Regression Equation:

$$Y = -1304 + 1.885X$$

Where:

Y = Compressive strength, in psi, using 6"x12" cylinders
X = Compressive strength, psi, using 4"x8" cylinders
R^2 = Square of the correlation coefficient = 0.844

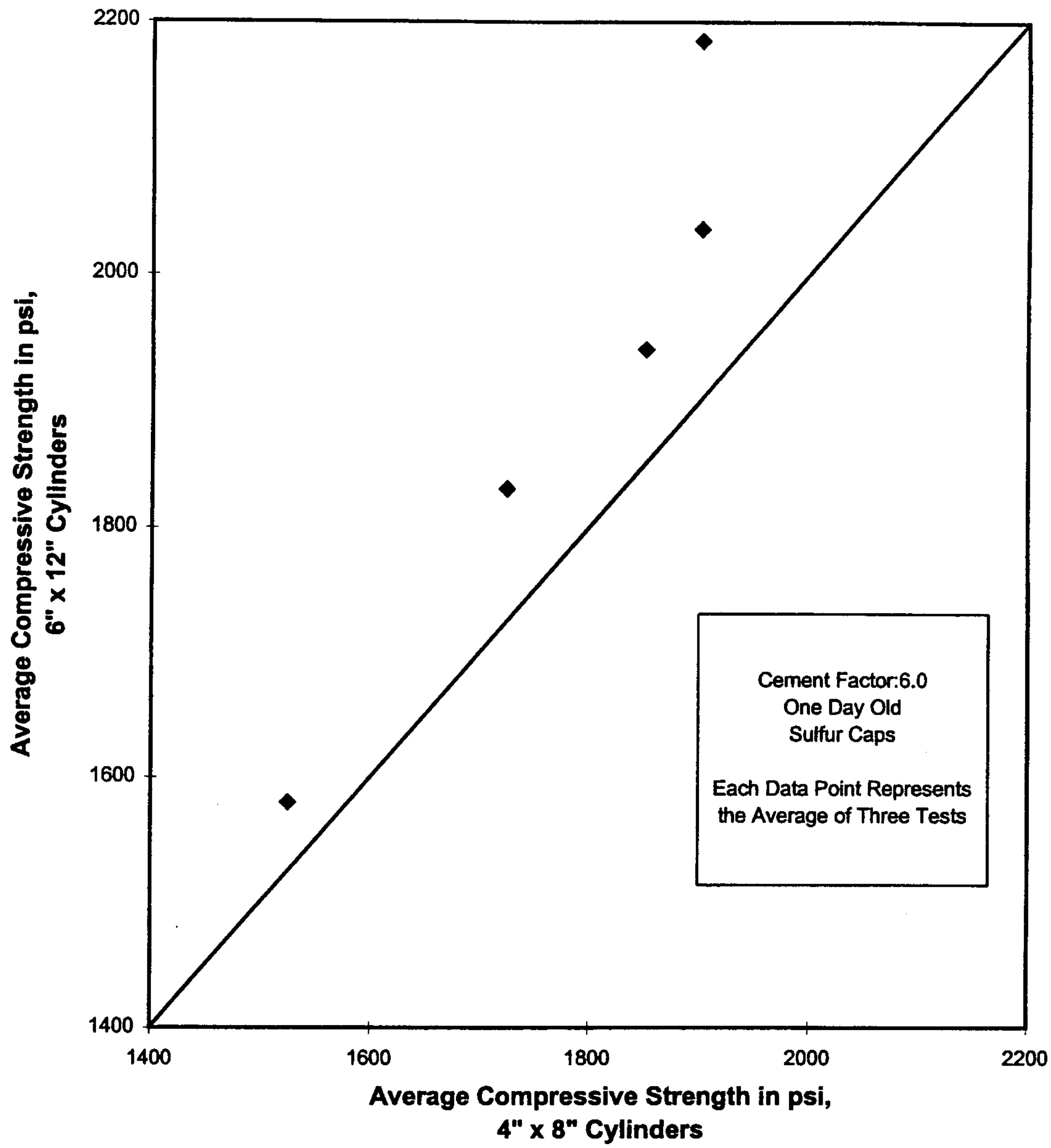

Figure 4.10. AverageCompressive Strengths of Different Size Concrete Cylinders

Regression Equation:

$$Y = -503 + 1.358X$$

Where:

Y = Compressive strength, in psi, using 6"x12" cylinders
X = Compressive strength, psi, using 4"x8" cylinders
R^2 = Square of the correlation coefficient = 0.911

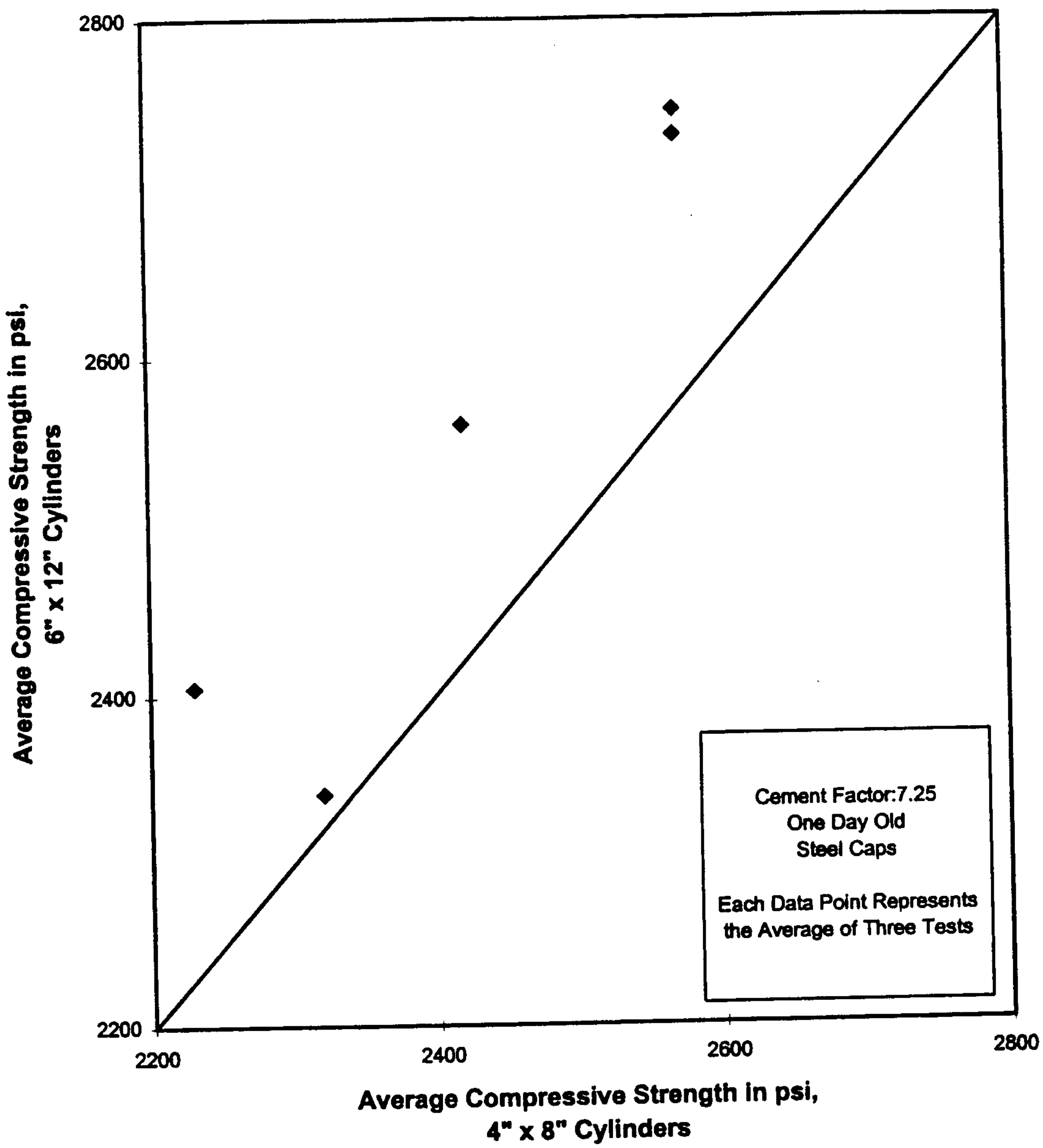

Figure 4.11. Average Compressive Strengths of Different Size Concrete Cylinders

Regression Equation:

$$Y = 255.6 + 1.161X$$

Where:

Y = Compressive strength, in psi, using 6"x12" cylinders
X = Compressive strength, psi, using 4"x8" cylinders
R^2 = Square of the correlation coefficient = 0.893

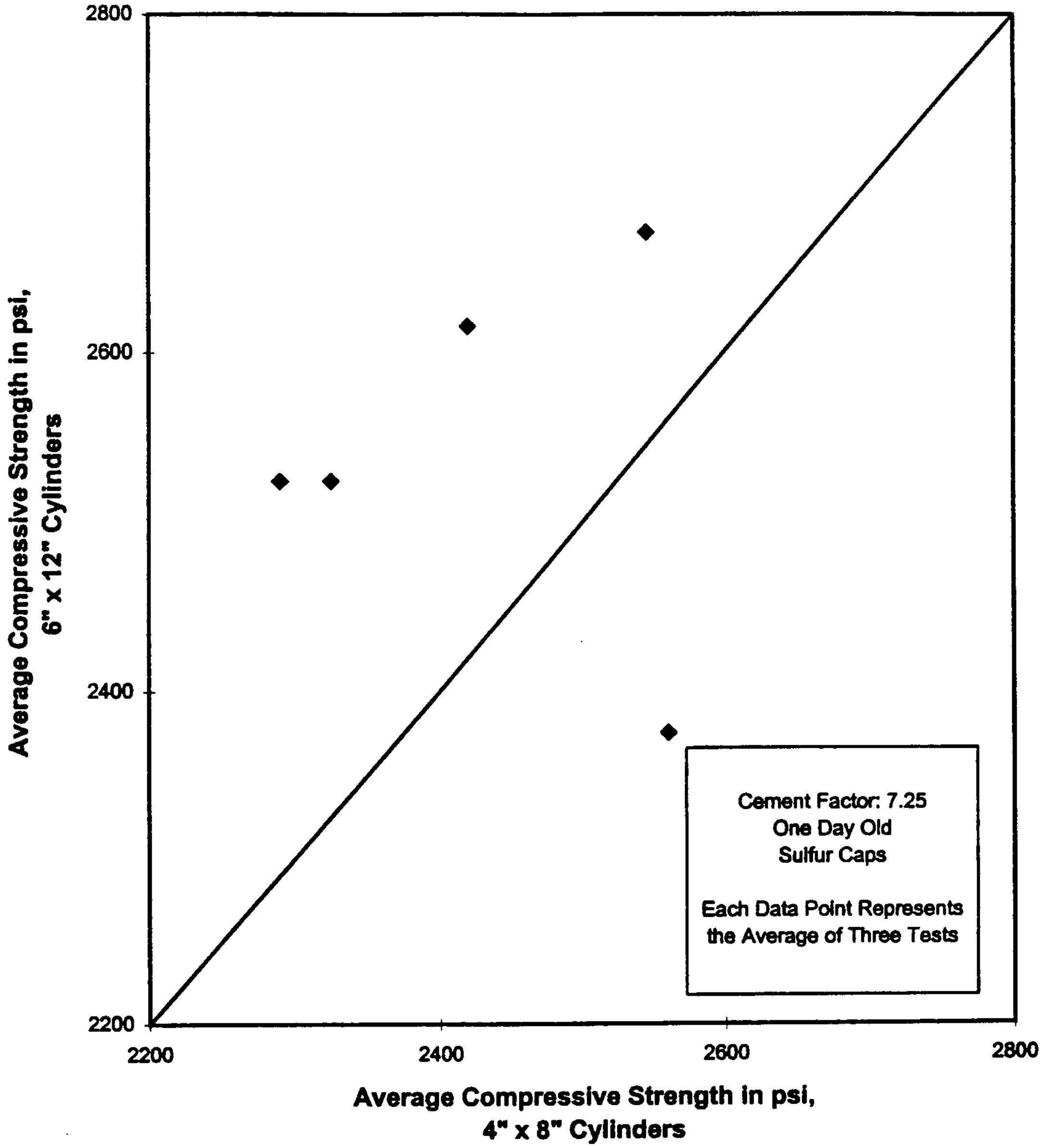

Figure 4.12. Average Compressive Strengths of Different Size Concrete Cylinders

Regression Equation:

$$Y = 2703 - 0.067X$$

Where:

Y = Compressive strength, in psi, using 6"x12" cylinders
X = Compressive strength, psi, using 4"x8" cylinders
R^2 = Square of the correlation coefficient = 0.005

Table 4.2 shows within-test statistics calculated for the results of compressive strength for all one day old specimens tested. The statistics include within-test averages, within-test standard deviations and within-test coefficients of variation of compressive strength.

Table 4.2. Average (psi), Within-test Standard Deviation (psi), and Within-test Coefficient of Variation (Percent) of Compressive Strength at One Day Old

Cement Factor		4" x 8"		6" x 12"	
		Steel/Neoprene	Sulfur Mortar	Steel/Neoprene	Sulfur Mortar
5.0	$\bar{x}$	1293	1363	1424	1515
	σ	43	42	85	38
	v	3.3	3.1	6.0	2.5
6.0	$\bar{x}$	1668	1781	1841	1915
	σ	75	69	95	55
	v	4.5	3.9	5.2	2.9
7.25	$\bar{x}$	2420	2429	2556	2542
	σ	77	72	87	189
	v	3.2	3.0	3.4	7.4

The within-test standard deviations of compressive strength at one day old were similar for all test results with the same cement factor throughout the data for the four inch diameter specimens. For those batches prepared with five bags of cement per cubic yard, the within-test standard deviation for the specimens tested with steel end caps was 43 psi. For those tested with sulfur mortar caps, the within-test standard deviation was 42 psi. For the batches prepared with six bags of cement per cubic yard, the within-test standard deviation for the specimens tested with sulfur mortar caps was 69 psi. The within-test standard deviation for those specimens tested with the steel end caps was 75 psi. For the batches prepared with 7.25 bags of cement per cubic yard, the within-test standard deviation was 77 psi for the specimens tested with steel and caps and 72 psi for those tested with sulfur mortar caps. Those specimens tested with sulfur mortar caps showed smaller standard deviations than those tested with steel end caps.

For the six inch diameter specimens, the within-test standard deviations for batches prepared with five bags of cement per cubic yard were 85 psi for the specimens tested with steel end caps and 38 psi for those tested with sulfur mortar caps. For mixes containing six bags of cement per cubic yard, the within-test standard deviation for the specimens tested with sulfur mortar caps was 55 psi. The within-test standard deviation for those tested with steel end caps was 95 psi. For the batches prepared with 7.25 bags of cement per cubic yard, the within-test standard deviation for the specimens tested sulfur mortar caps was 189 psi while it was 87 psi for the specimens tested with steel end caps. For batches prepared with 7.25 bags of cement per cubic yard, the specimens tested with stel end caps were less variable than their counterparts tested with sulfur mortar caps. However, one observation for the sulfur mortar caps was considerably lower than the others (Table B-5, Batch No. 13). If this value were excluded as an outlier, the within – test standard deviation for the sulfur mortar caps would be significantly reduced.

For four inch diameter cylinders, the within-test coefficients of variation at one day old tended to be similar for the different capping media for all three cement contents tested. For the batches prepared with five bags of cement per cubic yars, coefficients of variation varied by 0.2%, 3.3% for the specimens tested with steel end caps and 3.1% for those specimens tested with sulfur mortar caps. For the mixes made with six bags of cement per cubic yard, the coefficients of variation differed by 0.6%, the largest variation of the three cement contents. The specimens tested with steel end caps showed a within-standard deviation was 77 psi for the specimens tested with steel and caps and 72 psi for those tested with sulfur mortar caps. Those specimens tested with sulfur mortar caps showed smaller standard deviations than those tested with steel end caps.

For the six inch diameter specimens, the within-test standard deviations for batches prepared with five bags of cement per cubic yard were 85 psi for the specimens tested with steel end caps and 38 psi for those tested with sulfur mortar caps. For mixes containing six bags of cement per cubic yard, the within-test standard deviation for the specimens tested with sulfur mortar caps was 55 psi. The within-test standard deviation for those tested with steel end caps was 95 psi. For the batches prepared with 7.25 bags of cement per cubic yard, the within-test standard deviation for the specimens tested sulfur mortar caps was 189 psi while it was 87 psi for the specimens tested with steel end caps. For batches prepared with 7.25 bags of cement per cubic yard, the specimens tested with stel end caps were less variable than their counterparts tested with sulfur mortar caps. However, one observation for the sulfur mortar caps was considerably lower than the others (Table B-5, Batch No. 13). If this value were excluded as an outlier, the within – test standard deviation for the sulfur mortar caps would be significantly reduced.

For four inch diameter cylinders, the within-test coefficients of variation at one day old tended to be similar for the different capping media for all three cement contents tested. For the batches prepared with five bags of cement per cubic yars, coefficients of variation varied by 0.2%, 3.3% for the specimens tested with steel end caps and 3.1% for those specimens tested with sulfur mortar caps. For the mixes made with six bags of cement per cubic yard, the coefficients of variation differed by 0.6%, the largest variation of the three cement contents. The specimens tested with steel end caps showed a within-test coefficient of variation of 4.5%, while the companion cylinders tested with sulfur mortar caps had a within-test coefficient of variation of 3.9%. For batches prepared with 7.25 bags of cement per cubic yard, within-test coefficients of variation varied by 0.2%. For the specimens tested using steel end caps, the calculated within-test coefficient of variation was 3.2%. for those specimens tested with sulfur mortar caps, the within-test coefficient of variation was calculated to be 3.0%. From these results, it is can be inferred that test results for one day old concrete cylinders with sulfur mortar caps are less variable than test results for specimens tested with steel end caps, although this difference seems small in most cases.

For six inch diameter specimens, the within-test coefficients of variation were more variable than those for the four inch specimens. For batches prepared with five bags of cement per cubic yard, specimens tested using steel end caps had a within-test coefficient of variation of 6.0%, while those cylinders tested with sulfur mortar caps exhibited a within-test coefficient of variation of 2.5%. for those specimens fabricated with batches containing six bags of cement per cubic yard, the within-test coefficient of variation for those tested using sulfur mortar caps was 2.9%. For the companion cylinders tested using steel end caps, the within-test coefficient of variation was 5.2%. For the mixes of 7.25 bags of cement per cubic yard, however, specimens tested with steel end caps exhibited a within-test coefficient of variation that was considerably less than those obtained with the sulfur mortar caps. If the low observation (Table B-5, Batch No. 13) was excluded as a outlier, this result would be reversed.

Table 4.3 shows the 95% confidence intervals for the mean compressive strength for one day old specimens. Results indicate that there is no overlap in the ranges for the different cement factors. This shows that there is a definite difference in measured compressive strength values even for specimens of such an early age. No conclusion can be reached for which type of capping media is better suited for these early tests because there is no visible trend showing one type of capping media giving a smaller range of results for all cement factors within a single specimen size.

Table 4.3. 95% Confidence Intervals for Compressive Strength (psi) at One Day Old

Cement Factor	4" x 8"		6" x 12"	
	Steel/Neoprene	Sulfur Mortar	Steel/Neoprene	Sulfur Mortar
5.0	1293 ± 200 1093 - 1493	1363 ± 161 1202 - 1524	1424 ± 132 1292 - 1556	1515 ± 153 1362 - 1668
6.0	1668 ± 125 1543 - 1793	1781 ± 200 1581 - 1981	1841 ± 258 1583 - 2099	1915 ± 283 1632 - 2198
7.25	2420 ± 186 2324 - 2606	2429 ± 155 2274 - 2584	2556 ± 229 2327 - 2785	2542 ± 139 2403 - 2681

4.1.2. Twenty-Eight Day Old Specimens

Statistics were computed from the results of unconfined compression tests performed on all 28 day old specimens. Overall averages, standard deviations and coefficients of variation of the compressive strength for all of the specimens tested at 28 days old can be seen in Table 4.4.

Table 4.4. Average (psi), Standard Deviation (psi), and Coefficient of Variation (Percent) of Compressive Strength at 28 Days

Cement Factor		4" x 8"		6" x 12"	
		Steel/Neoprene	Sulfur Mortar	Steel/Neoprene	Sulfur Mortar
5.0	$\bar{x}$	4926	5024	4847	4751
	σ	237	236	161	208
	v	4.8	4.7	3.3	4.4
6.0	$\bar{x}$	5836	5777	5402	5351
	σ	172	351	228	222
	v	2.9	6.1	4.2	4.2
7.25	$\bar{x}$	6387	6297	5953	5919
	σ	439	491	431	400
	v	6.9	7.8	7.2	6.8

As expected, the average compressive strength increased with increasing cement content. The strength values differed only slightly for the different capping media. The maximum percent difference in the compressive strength was about two percent. This difference was found in the testing of four inch diameter specimens made from batches containing five bags of cement per cubic yard.

For the four inch diameter specimens fabricated from mixes containing five bags of cement per cubic yard, the average strength of specimens tested using steel end caps was 4926 psi. For the companion cylinders tested with sulfur mortar caps, the average compressive strength was 5024 psi. For those batches made with six bags of cement per cubic yard, the average compressive strength for the specimens tested with sulfur mortar caps was 5777 psi. For the cylinders tested with steel end caps the average compressive strength was 5836 psi. For the batches prepared with 7.25 bags of cement per cubic yard, the average compressive strength from the specimens tested using steel end caps was

6387 psi. The average compressive strength for the companion cylinders tested with sulfur mortar caps was 6297 psi.

For six inch diameter speciments made with five bags of cement per cubic yard, the average compressive strength for the cylinders tested using steel end caps was 4847 psi. the average compressive strength for the companion cylinders tested with sulfur mortar caps was 4751 psi. For cylinders made from batches containing six bags of cement per cubic yard, the average compressive strength of the specimens tested with sulfur mortar caps was 5351 psi. The average compressive strength of cylinders tested using steel end caps was 5402 psi. For mixes containing 7.25 bags of cement per cubic yard, the average compressive strength for the specimens tested using steel end caps was 5953 psi. For companion cylinders tested with sulfur mortar caps, the average compressive strength was 5919 psi.

One trend observed from results of unconfined compressive strength of the 28 day old specimens was that six inch diameter specimens tested using steel end caps tended to give higher compressive strengths than specimens tested with sulfur mortar caps. Figures 4.13 through 4.15 show this trend graphically. The average of each set of three cylinders tested from each batch for each capping media was used in construction these figures. As before, the effects of the capping media on the measured compressive strengths were isolated in these figures. Results appear to indicate that six inch diameter specimens tested with steel end caps tend to have higher measured compressive strengths than comparable specimens tested with sulfur mortar caps.

Results in Table 4.4 indicate that for the 5.0 cement factor, the average compressive strengths of four inch diameter specimens capped with sulfur mortar are higher than that of those specimens capped using steel end caps and lower for the other

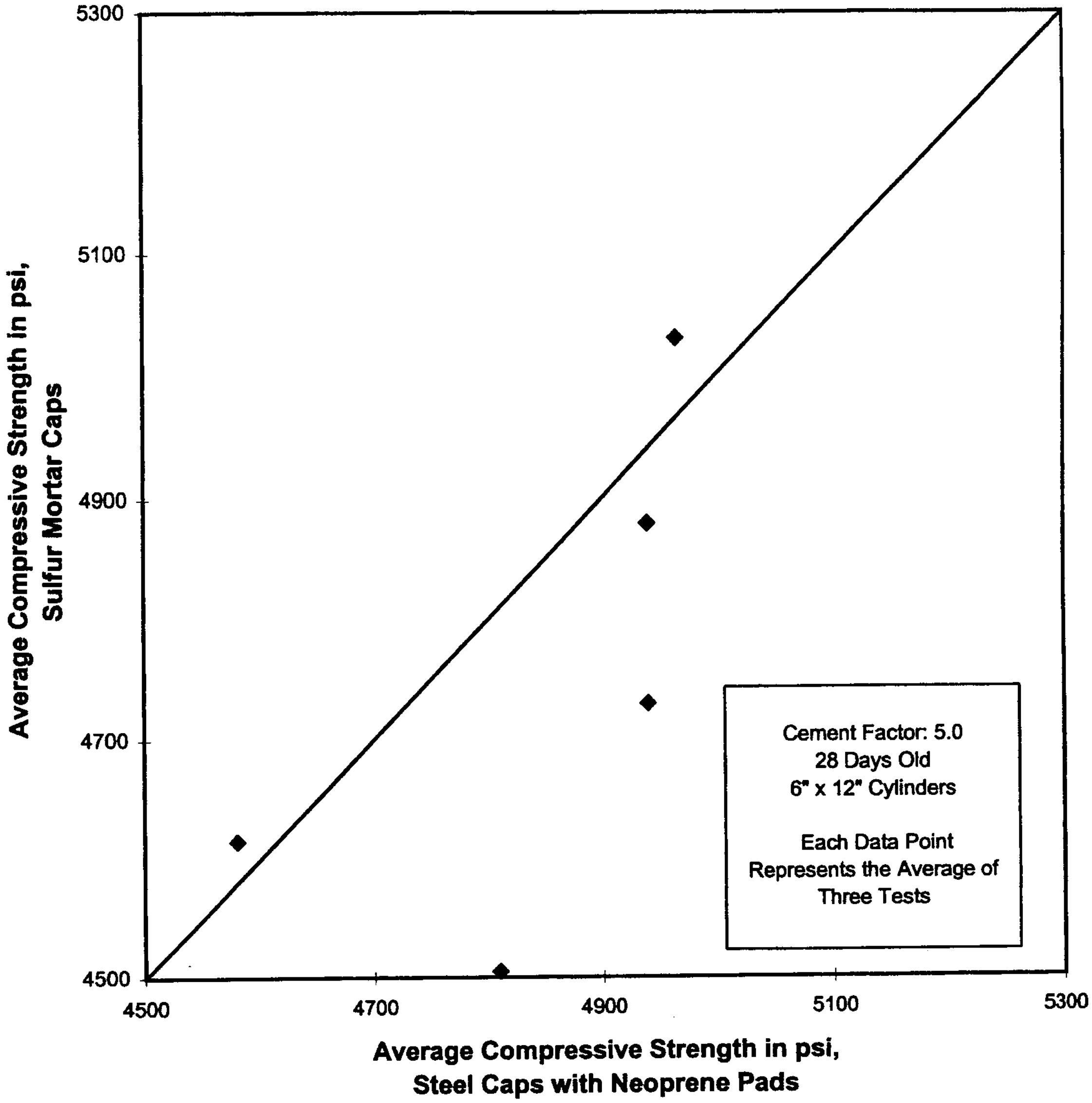

Figure 4.13. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

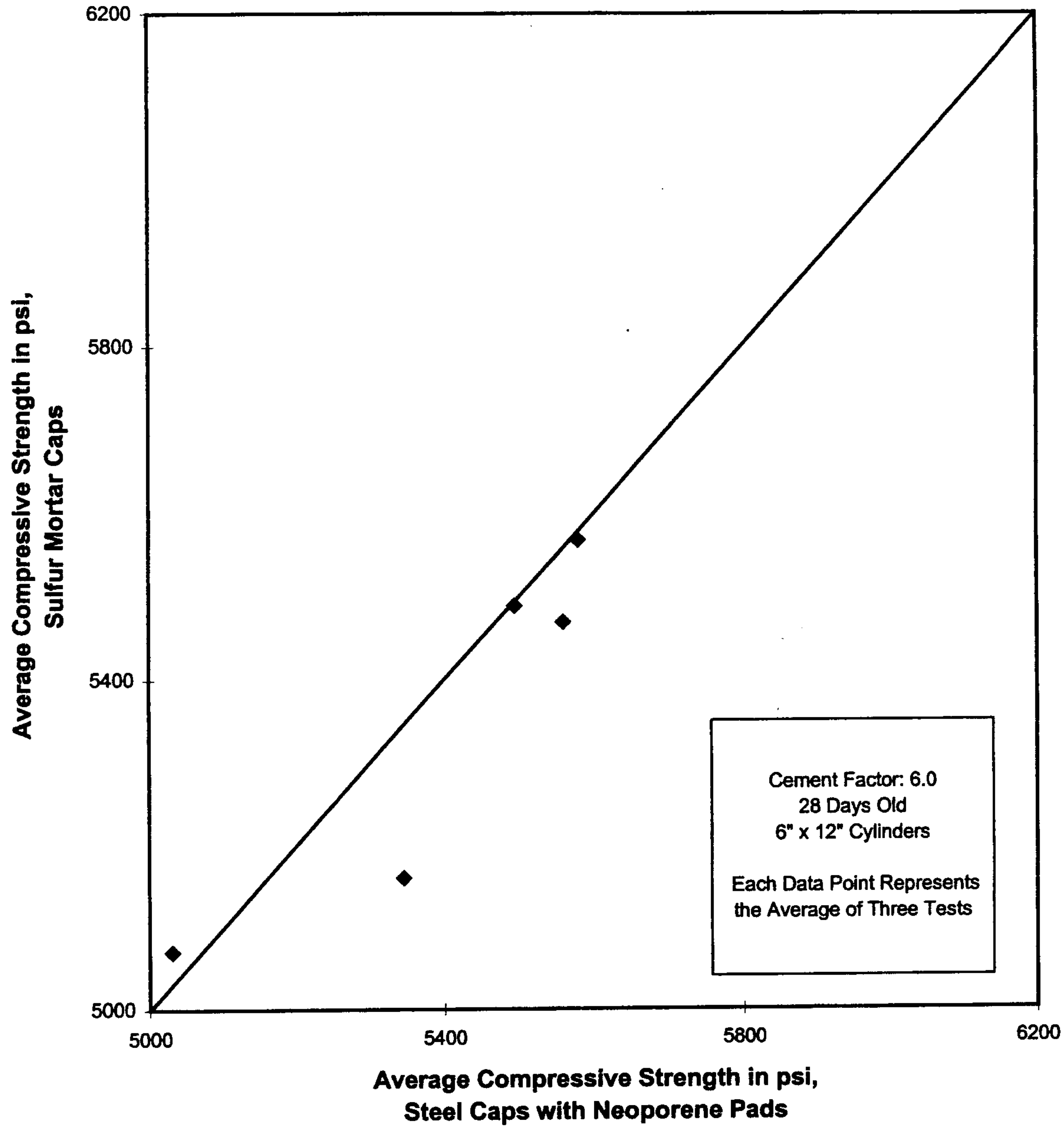

Figure 4.14. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

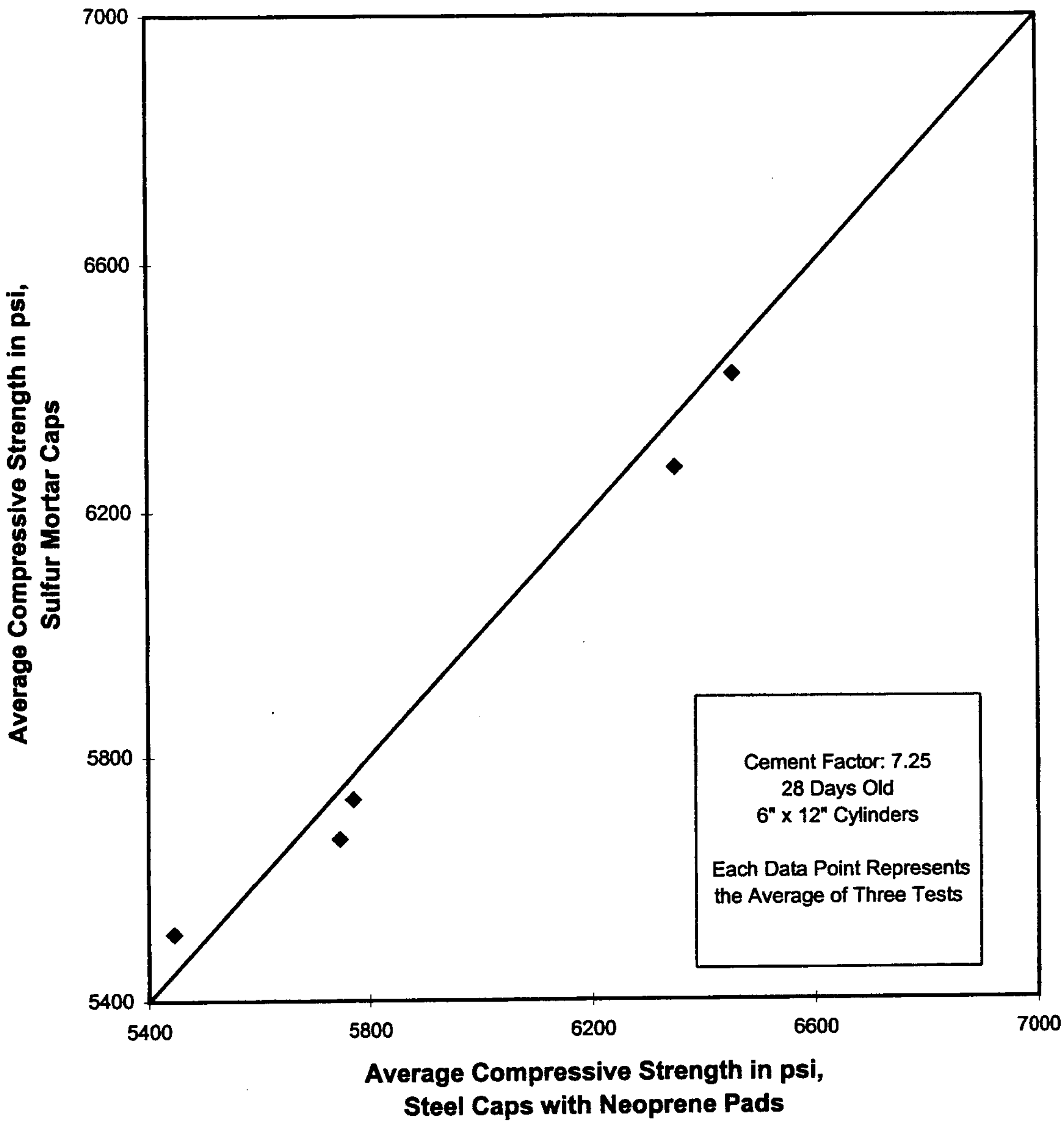

Figure 4.15. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

two cement factors. These results are plotted in Figures 4.16 through 4.18. These figures seem to show that as cement content increases, steel end caps tend to give higher compressive strengths than the specimens tested with sulfur mortar caps. In Figure 4.16, all average values for the different capping media tend to show that sulfur mortar caps give higher compressive strengths than steel end caps. In Figure 4.17, most of the results show that the specimens tested with steel end caps give higher compressive strengths than those tested with sulfur mortar caps. The trend in Figure 4.18 is the same as the trend as Figure 4.17.

Another trend observed consistently throughout this study was that small specimens showed higher measured compressive strengths than the conventional sized cylinders when tested at 28 days old. This is shown explicitly in Figures 4.19 through 4.24. In constructing these plots, the only factor varied was that of specimen size. It was observed that the results are grouped more closely toward the axis for the compressive strength results of four inch by eight inch cylinders, rather than toward that of the six inch by twelve inch cylinders. It was concluded that four inch diameter cylinders tend to give higher compressive strengths than companion six inch diameter cylinders.

The standard deviations can all be described as "fair" or better aws provisions of ACI214-77 (ACI, 1994) for batches with five and six bags of cement per cubic yard. The overall standard deviations for all of the batches with 7.25 bags of cement per cubic yard are classified as "poor," i.e. above 350 psi. This can probably be attributed to the wide range of slump data recorded for the batches with 7.25 bags of cement per cubic yard. The values recorded for the slumps were all either 2 5/8 inches or 3 ½ inches, with no

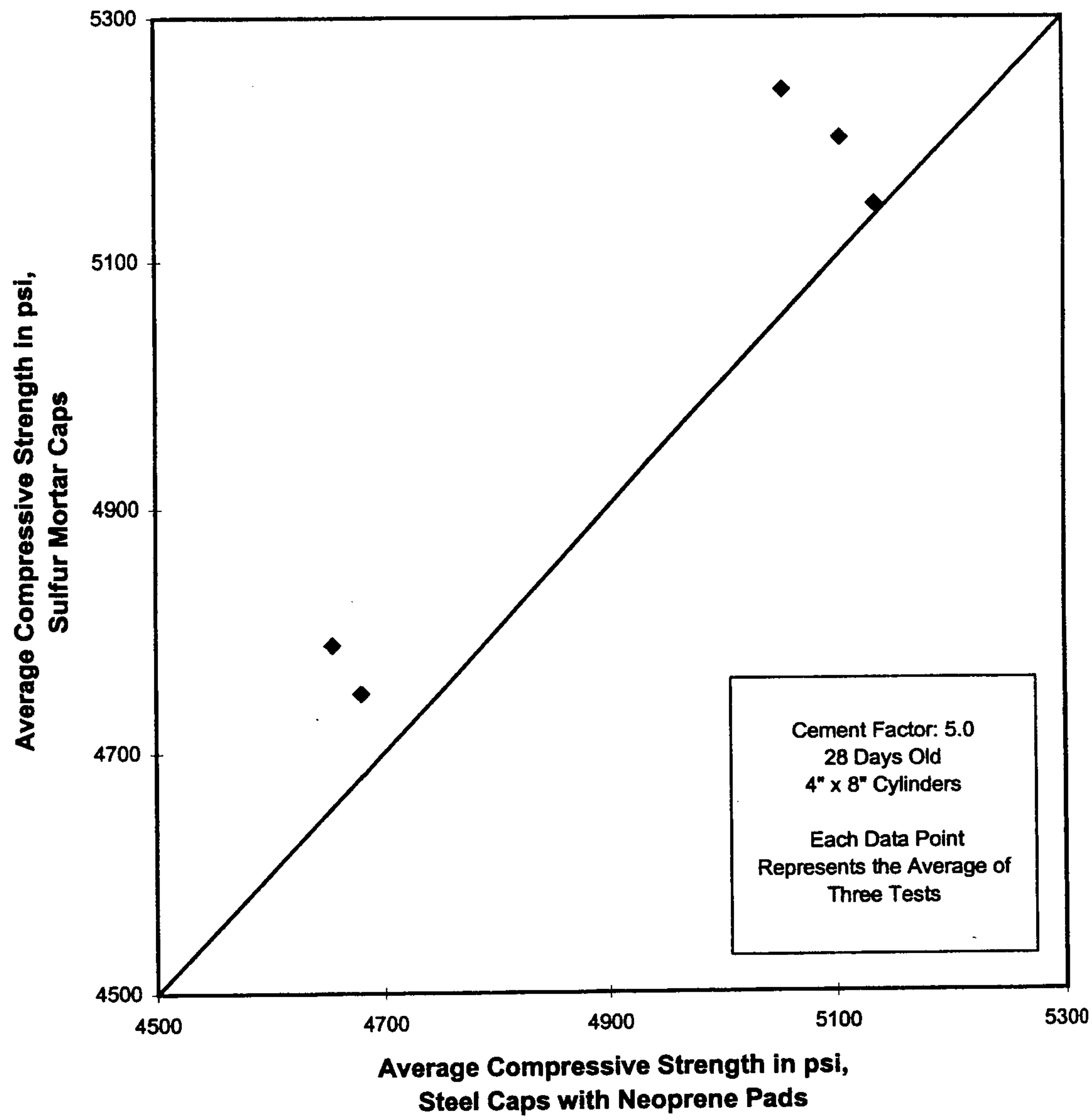

Figure 4.16. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

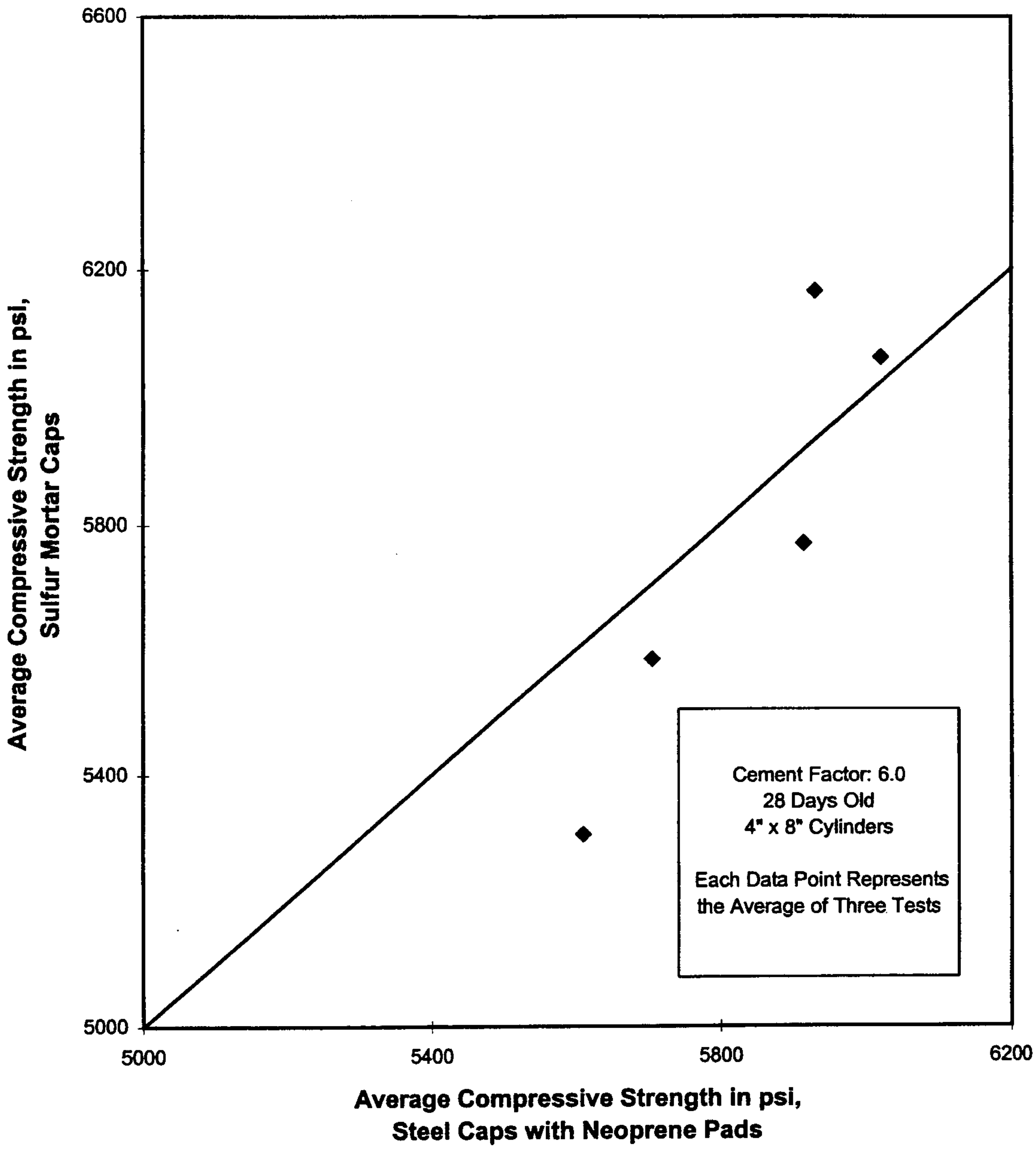

Figure 4.17. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

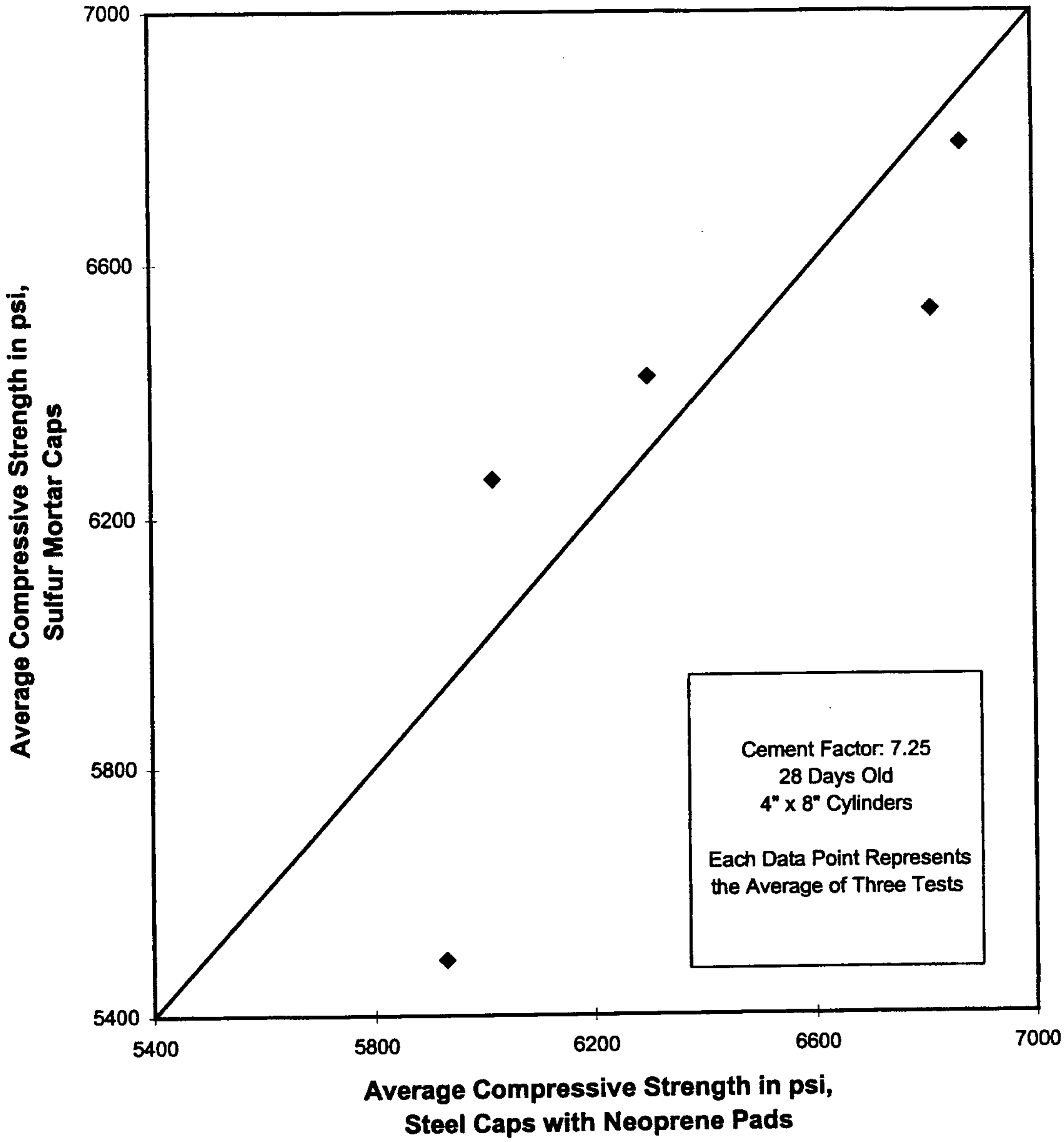

Figure 4.18. Average Compressive Strengths of Concrete Cylinders Tested with Different Capping Media

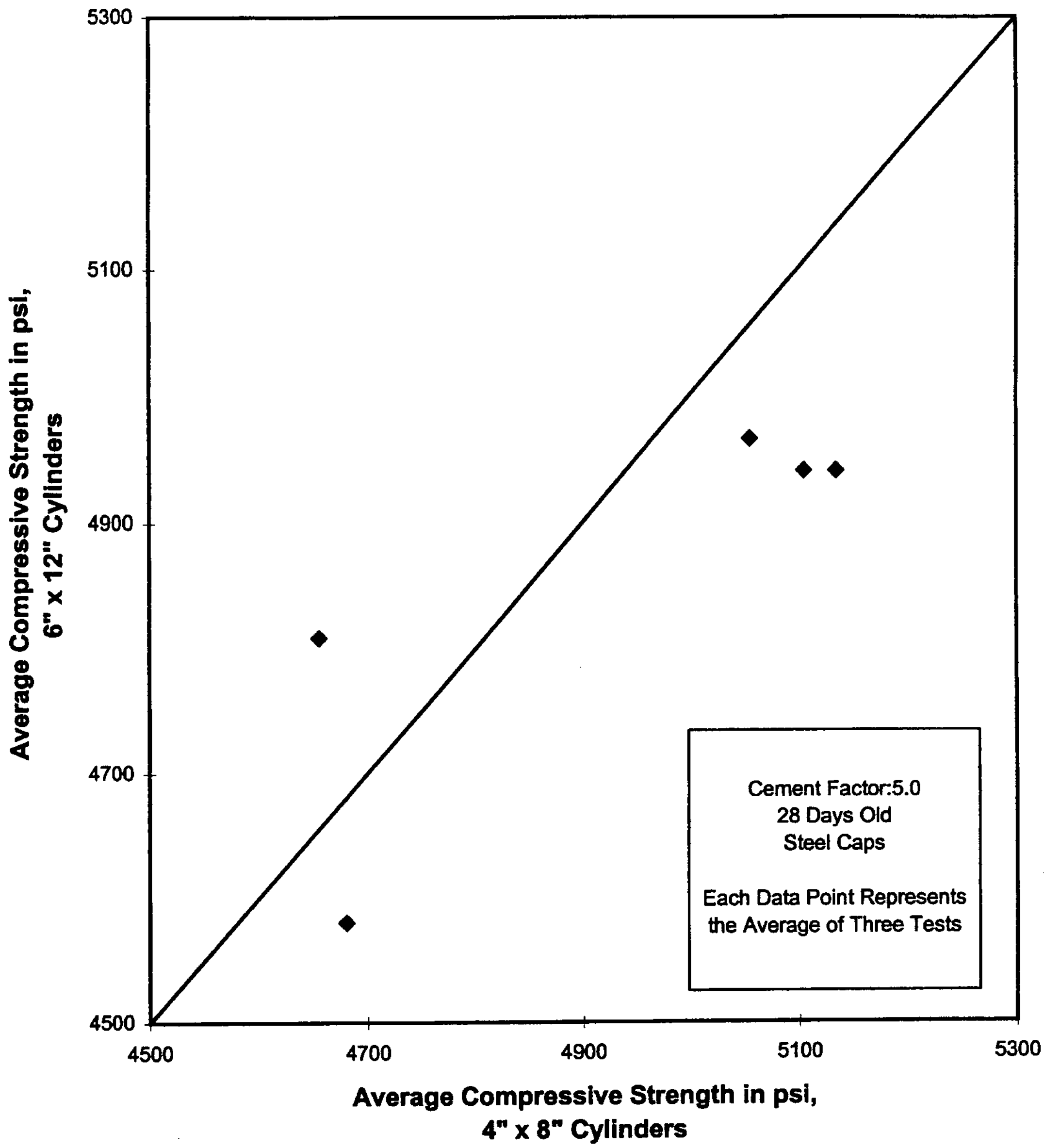

Figure 4.19. Average Compressive Strengths of Different Size Concrete Cylinders

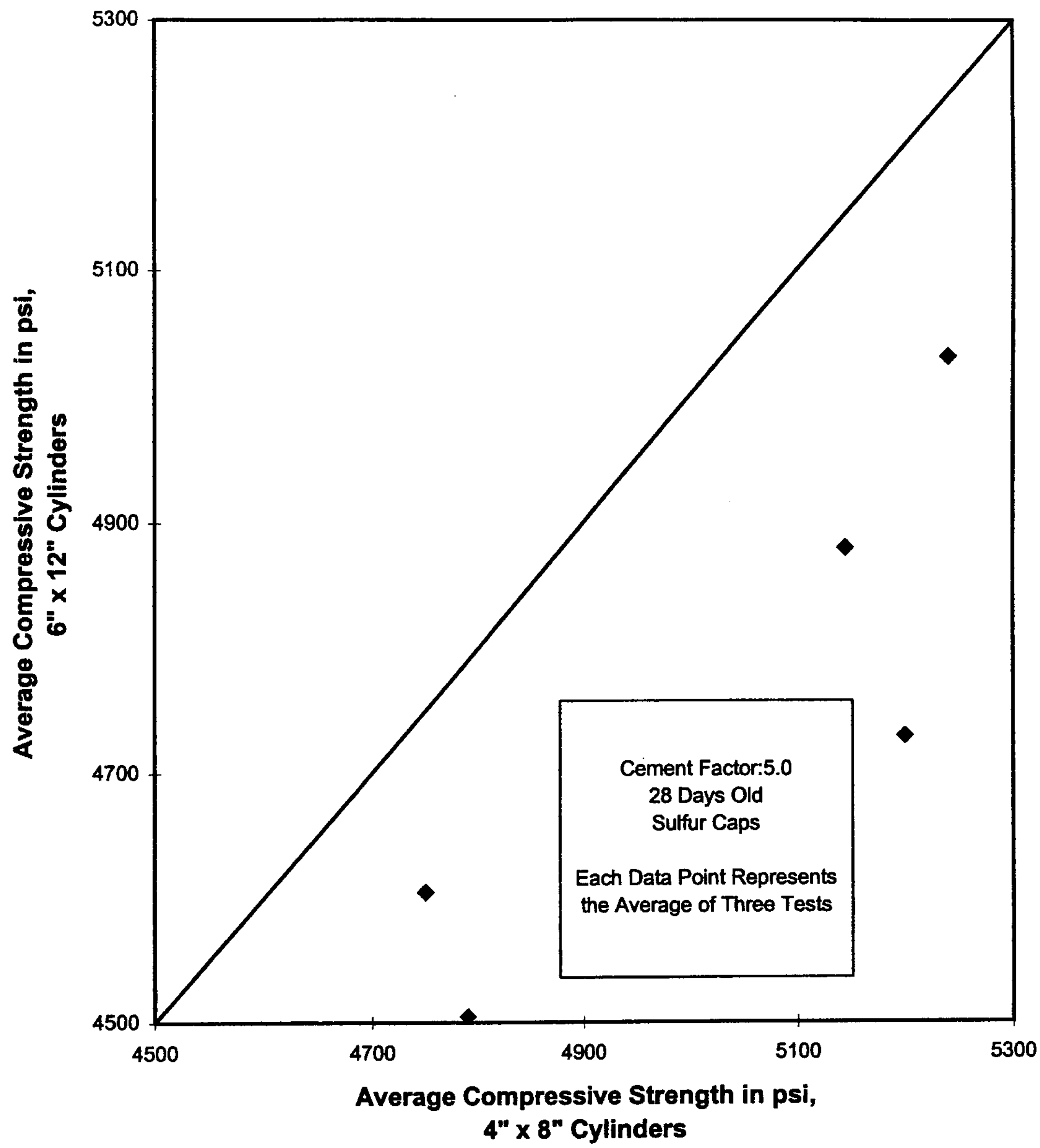

Figure 4.20. Average Compressive Strengths of Different Size Concrete Cylinders

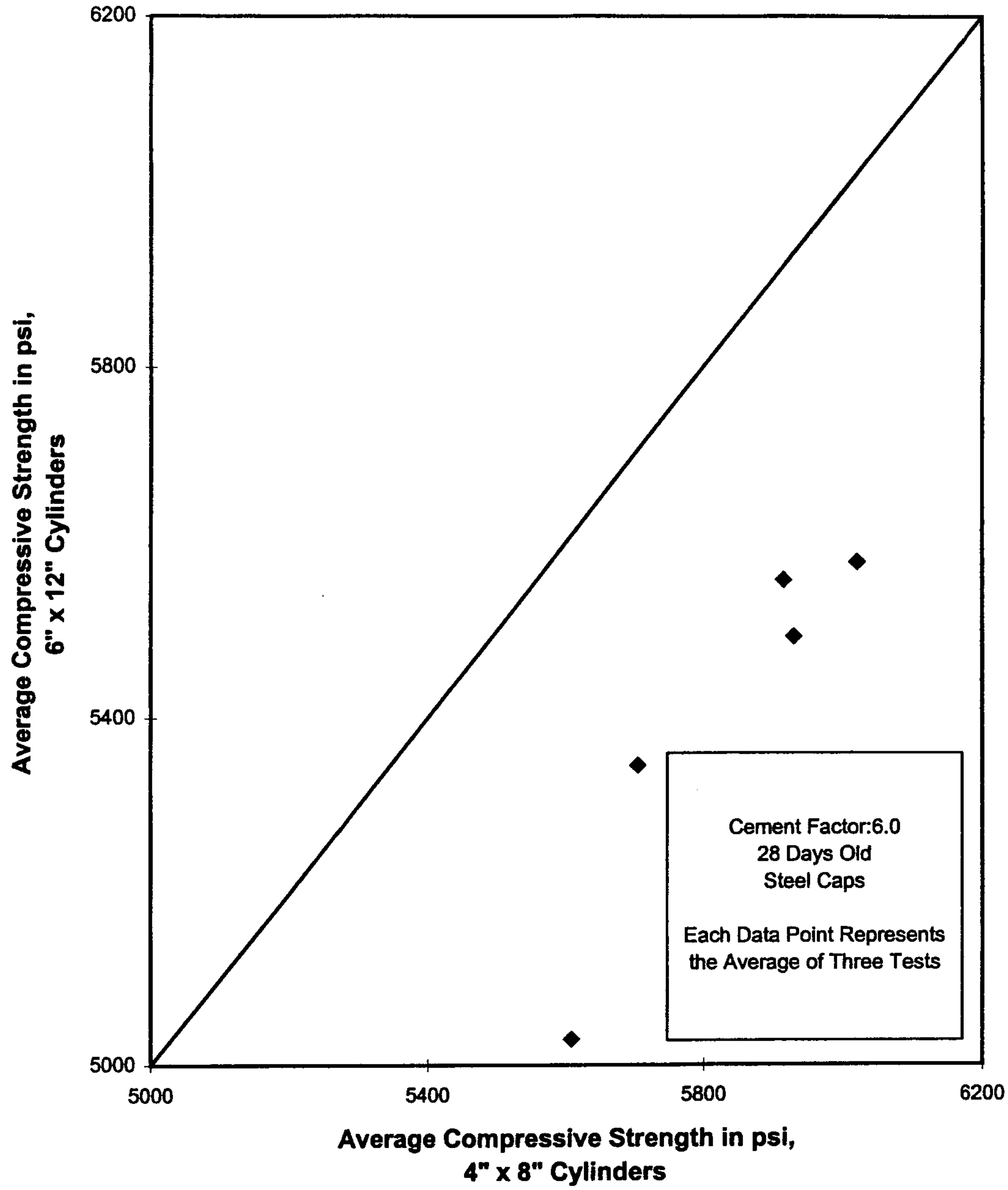

Figure 4.21. Compressive Strength of Different Size Concrete Cylinders

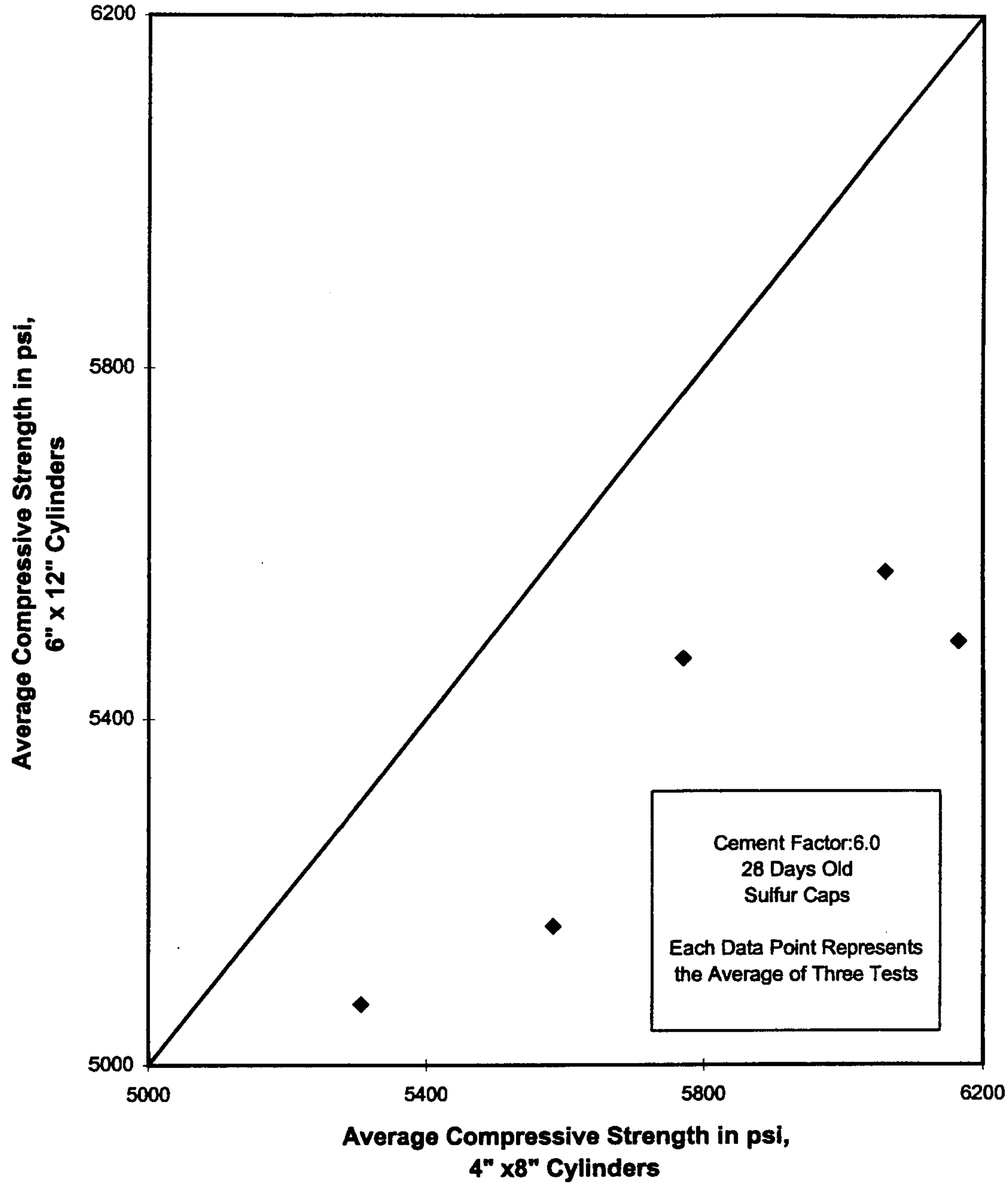

Figure 4.22. Compressive Strength of Different Size Concrete Cylinders

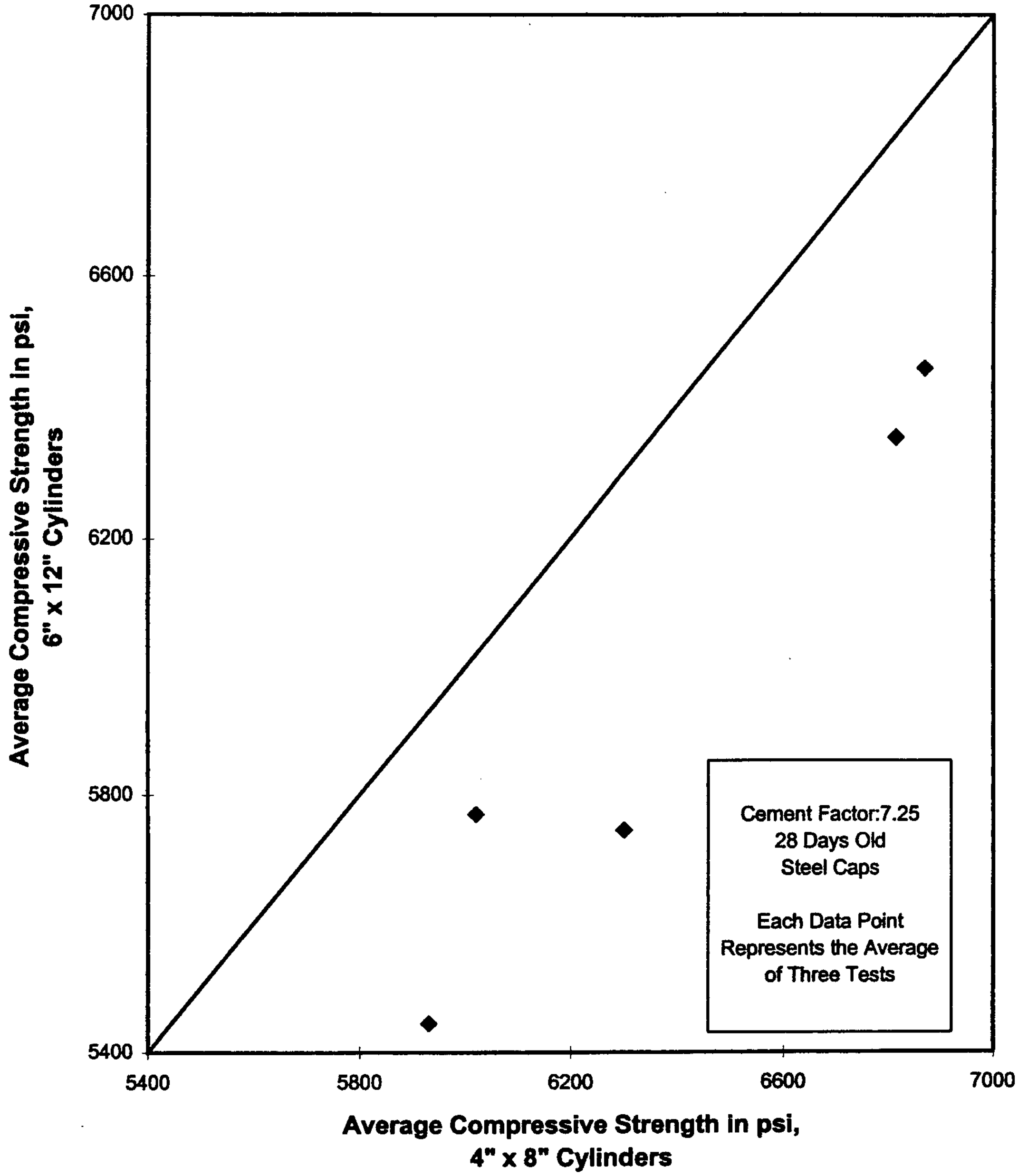

Figure 4.23. Average Compressive Strengths of Different Size Concrete Cylinders

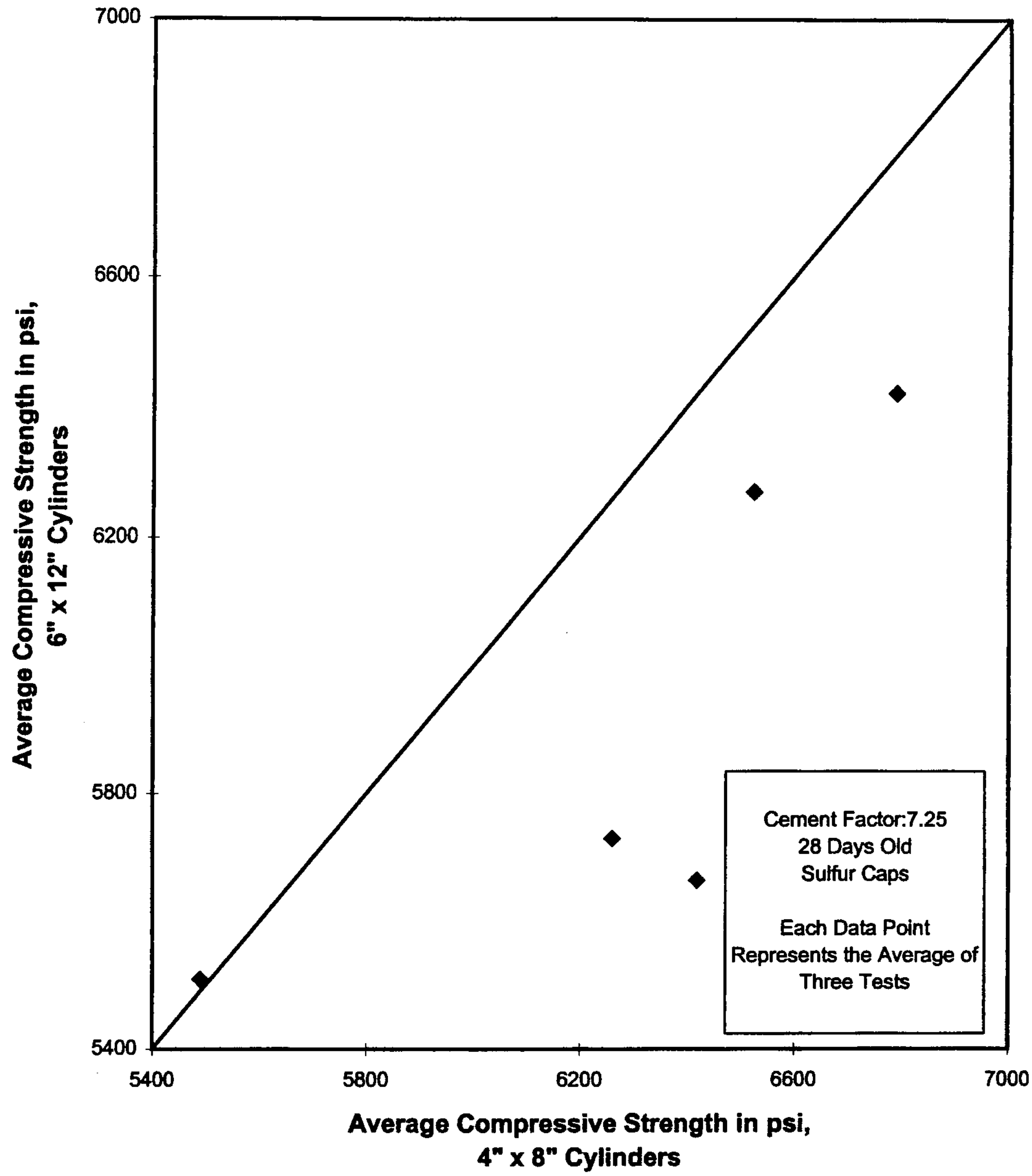

Figure 4.24. Compressive Strength of Different Size Concrete Cylinders

values in between. The range of slump values for the mixes containing 7.25 bags of cement per cubic yard was ⅞ of an inch. This represents the largest spread of slump values for the three different cement contents. This could have lead to the widespread variation in the compressive strength results for the batches containing 7.25 bags of cement per cubic yard.

The coefficients of variation for most of the batches containing five and six bags of cement per cubic yard fall within the "excellent" range according to ACI 214-65, less than five percent. An exception was the results of the four inch diameter specimens containing six bags of cement per cubic yard and tested using sulfur mortar capping material. These results exhibited a "good" coefficient of variation, 6.1%. Coefficients of variation for most of the data for the batches containing 7.25 bags of cement per cubic yard fall within the "good" range (5.0% - 7.0%) with the exception of the six inch diameter specimens capped with the steel end caps with removable neoprene inserts, which were slightly less than "good" at a coefficient of variation of 7.2%, and the four inch diameter specimens tested with sulfur mortar caps, giving a coefficient of variation of 7.8%.

Table 4.5. Average (psi), Within-test Standard Deviation (psi) and Within-test Coefficient of Variation (Percent) of Compressive Strength at 28 Days Old

Cement Factor		4" x 8"		6" x 12"	
		Steel/Neoprene	Sulfur Mortar	Steel/Neoprene	Sulfur Mortar
5.0	$\bar{x}$	4926	5024	4847	4751
	σ	106	68	87	194
	v	2.2	1.4	1.8	4.1
6.0	$\bar{x}$	5836	5777	5402	5351
	σ	120	278	103	116
	v	2.0	4.8	1.9	2.2
7.25	$\bar{x}$	6387	6297	5953	5919
	σ	149	405	106	82
	v	2.3	6.4	1.8	1.4

The within-test coefficients of variation can all be categorized as "very good" or better for results of the compressive strength for most batches. A coefficient of variation of less than 2.0% rates as "excellent" and a value between 2.0% and 3.0% rates as "good" (ACI, 1994). Three exceptions to this would be six inch diameter specimens with five bags of cement per cubic yard tested with sulfur mortar caps, four inch diameter specimens with six bags of cement per cubic yard tested with sulfur mortar caps and four inch diameter specimens with 7.25 bags of cement per cubic yard tested with sulfur mortar caps. The coefficients of variation for these three cases are 4.1%, 4.8% and 6.4%, respectively, and they can all be categorized as "poor" (ACI, 1994). This shows that sulfur mortar caps tend to be more variable than steel caps when testing comparable specimens at 28 days old.

Table 4.6 shows the 95% confidence intervals for the compressive strength results of the specimens tested at 28 days old. There is no overlap shown between the measured compressive strengths for the specimens made with batches containing five bags of cement per cubic yard and six bags of cement per cubic yard. The batches made with 7.25 bags of cement per cubic yard have the largest variations of the different mixes and, consequently, the lower end of the range for the batches made with 7.25 bags of cement per cubic yard overlaps with the upper part of the range for the batches made with six bags of cement per cubic yard.

Table 4.6. 95% Confidence Intervals for the Compressive Strength at 28 Days Old

Cement Factor	4" x 8"		6" x 12"	
	Steel/Neoprene	Sulfur Mortar	Steel/Neoprene	Sulfur Mortar
5.0	4926 ± 294 4632 - 5220	5024 ± 293 4731 - 5317	4847 ± 200 4647 - 5047	4751 ± 258 4493 - 5009
6.0	5836 ± 213 5623 - 6049	5777 ± 436 5341 - 6213	5402 ± 283 5119 - 5685	5351 ± 276 5075 - 5627
7.25	6387 ± 544 5843 - 6931	6297 ± 609 5688 - 6906	5953 ± 534 5419 - 6487	5919 ± 497 5423 - 6417

4.2. Analysis of Variance

From the results of the unconfined compressive strength tests an analysis of variance was performed to investigate the effect of type of capping, specimen size, length of curing time, cement content and various interactions between these factors. The results of the analysis of variance appear in Table 4.7.

Table 4.7. Results of the Analysis of Variance

Source of Variation	Significant? (Alpha=.05)
Curing Time (CT)	Yes
Cement Factor (CF)	Yes
Dimensions (Dim)	Yes
Capping (Cap)	No
CT*CF	Yes
CT*Dim	Yes
CT*Cap	No
CF*Dim	No
CF*Cap	No
Dim*Cap	No
CT*CF*Dim	No
CT*CF*Cap	No
CT*Dim*Cap	No
CF*Dim*Cap	No
CT*CF*Dim*Cap	No

From the results of the analysis of variance it was found that, at an α level equal to 0.05, specimen curing time, cement content of the mix, and specimen dimensions were all significant factors in the differences of the results of compressive strength when the specimens were tested in unconfined compression. Type of capping media did not affect the results of the unconfined compression tests at this level of significance. Of the different interactions between these factors, the only interactions that were found to have an effect on the compressive strength were the interaction between curing time and cement content and curing time and dimension. Results of other interactions investigated, of which none were found to have a significant effect on the compressive strength results, are found in Table 4.7.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The following conclusions appear warranted based on analyses of results of unconfined compressive strength tests performed on different size concrete cylinders capped with either steel caps with removable neoprene inserts or sulfur mortar material:

1. Steel end caps with removable neoprene inserts can serve as an acceptable capping media for four inch diameter concrete cylinders that are either one or twenty eight days old when tested in unconfined compression. "Acceptable" means that steel end caps or sulfur mortar caps can be used interchangeably when testing these specimens.
2. Steel end caps with removable neoprene inserts can serve as an acceptable capping media for one day old six inch diameter concrete cylinders tested in unconfined compression.
3. One day old, six inch diameter concrete cylinders tested in unconfined compression are stronger than comparable four inch diameter specimens.
4. Twenty eight day old, four inch diameter concrete cylinders tested in unconfined compression are stronger than comparable six inch diameter specimens.

5. The West Virginia Department of Highways may wish to change Section 601.4 of the Standard Specifications to allow use of steel end caps when testing early age concrete cylinders in unconfined compression.

5.2. Suggestions for Future Research

The following suggestions are made based on the results of the study reported here:

1. Research should be undertaken to determine why, at an age of one day, conventional sized cylinders exhibit greater compressive strengths than small specimens while at an age of twenty eight days, the smaller cylinders exhibit greater compressive strengths than conventional sized cylinders. Results of this research would be of interest to those trying to predict strength of aged concrete from results of tests of young concrete.
2. Additional study should be done to correlate the strength of young concrete with 28 day old specimen strength. Such work could help expedite testing of concrete for purposes of minimum strength attainmen, which in turn, could make it more feasible to remove unacceptable concrete before removal becomes either impossible or impractical.
3. Research should be undertaken to investigate if the results of this study, limited to a single lab and operator, would be repeatable in a multi-lab setting. This would be of interest to agencies that deal with various testing laboratories

for the strength assessment of concrete tested from various projects under such an agency's control.

4. Additional study should be done to determine if the results obtained in this study could be repeated using concretes of different constituents. This study examined typical concrete made with locally available aggregates from this geographic area. Other areas use concrete with aggregates of different type, shape and texture, usually depending on types that are locally available. Other differences could be the addition of various admixtures, such as water reducers, retarders or accelerators, in areas where these admixtures are regularly used in everyday concrete work.

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West Virginia Department of Transportation - Division of Highways, Standard Specifications for Roads and Bridges, 1994.

APPENDIX A:

Materials and Proportions

Table A.1. Coarse Aggregate Sieve Analysis
(Averages from Five Samples)

Sieve	Weight Retained (g)	Percent Retained	Cumulative Percent Retained	Percent Passing
1 ½"	0	0	0	100
1"	1335	8.7	8.7	91.3
½"	10,052	65.5	74.2	25.8
#4	2640	17.2	91.4	8.2
#8	967	6.3	97.7	2.3
Pan	353	2.3	100	---

Average Sample Size: 15,350 grams

Gradation corresponds to #57 according to ASTM C33

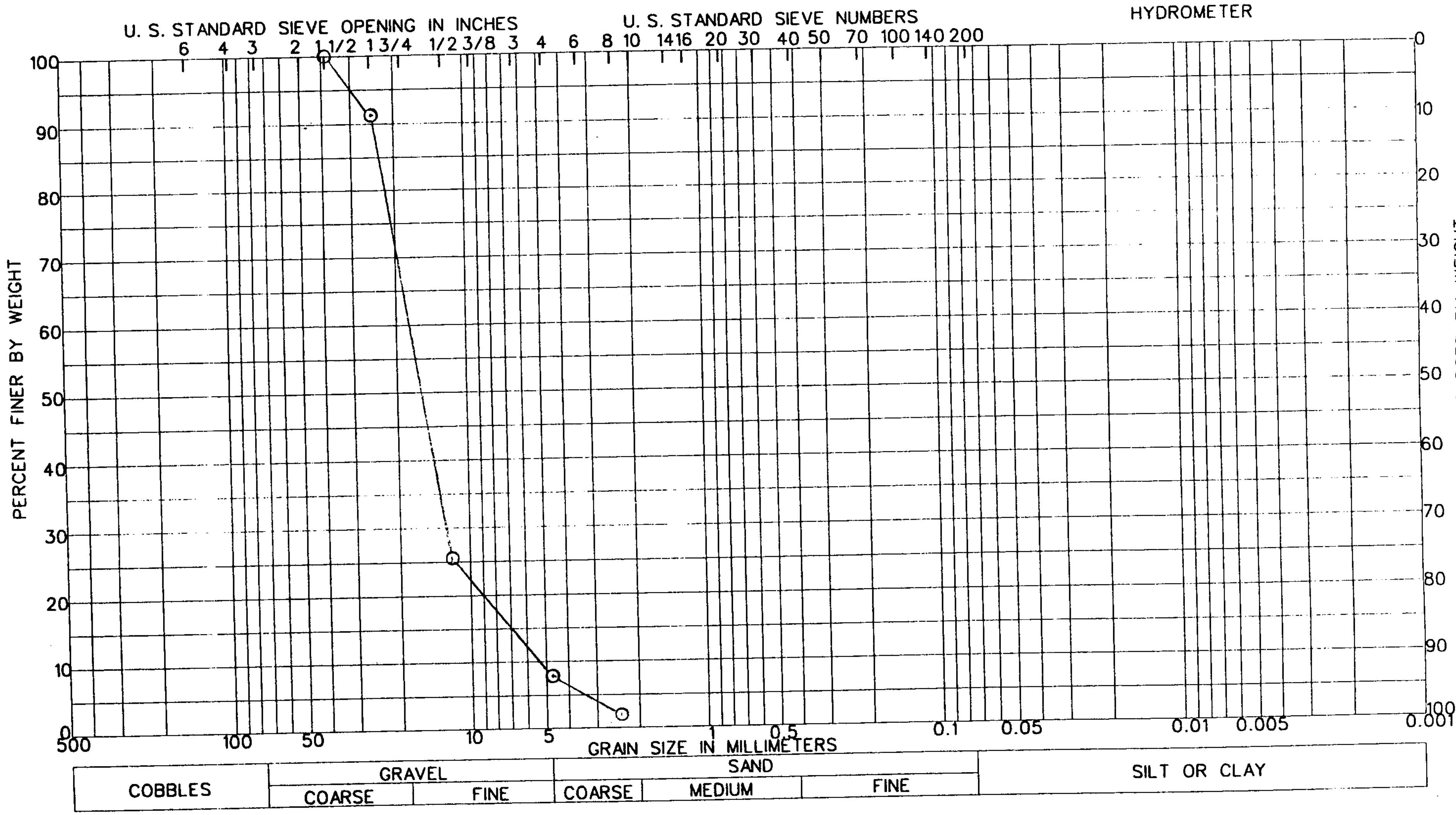

Figure A.1. Gradation for Screen Analysis of Coarse Aggregate

Table A.2. Fine Aggregate Sieve Analysis
(Averages from Five Samples)

Sieve	Weight Retained (g)	Percent Retained	Cumulative Percent Retained	Percent Passing
1 ½"	0	0	0	100
3/4"	0	0	0	100
3/8"	0	0	0	100
#4	22	2.8	2.8	97.1
#8	79	10.3	13.1	86.9
#16	90	11.7	24.8	75.2
#30	179	23.3	48.1	51.9
#50	276	35.8	83.9	16.1
#100	97	12.6	96.5	3.5
#200	18	2.4	98.9	1.1
Pan	7	0.9	99.8	---

Average Sample Size: 770 grams

$\bar{A}_5 = 6.32$

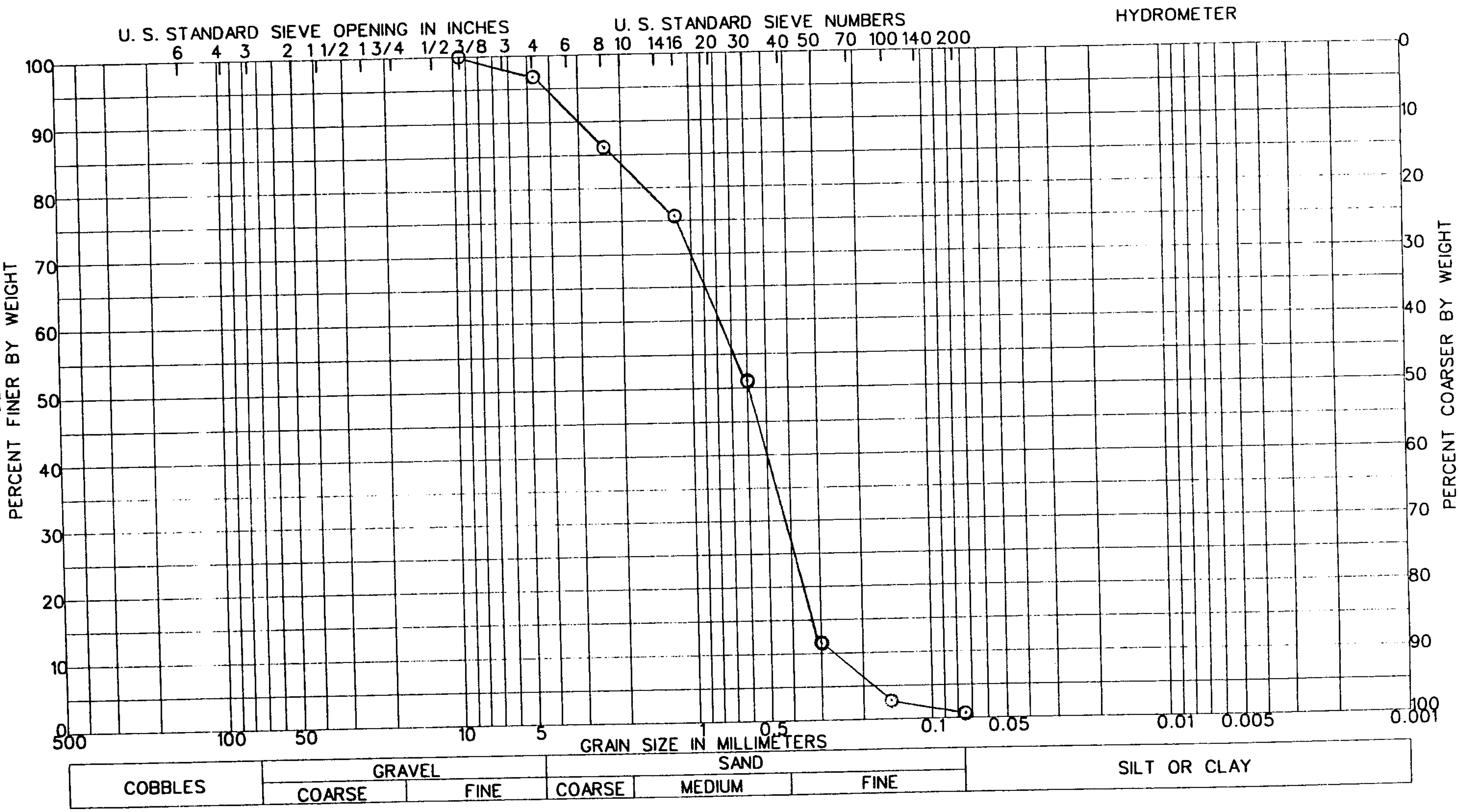

Figure A.2. Gradation for Sieve Analysis of Fine Aggregate

Table A.3. Washed Fine Aggregate Sieve Analysis
(Averages from Five Samples)

Sieve	Weight Retained (g)	Percent Retained	Cumulative Percent Retained	Percent Passing
1 ½"	0	0	0	100
3/4"	0	0	0	100
3/8"	0	0	0	100
#4	21	2.8	2.8	97.2
#8	75	10.2	13.0	87.0
#16	82	11.2	24.2	75.8
#30	146	19.9	44.1	55.9
#50	277	37.7	81.8	18.2
#100	99	13.4	95.2	4.8
#200	19	2.6	97.8	2.2
Wash	14	2.1	99.9	---
Pan	2			

Average Sample Size: 736 grams

$\bar{A}_5 = 6.41$

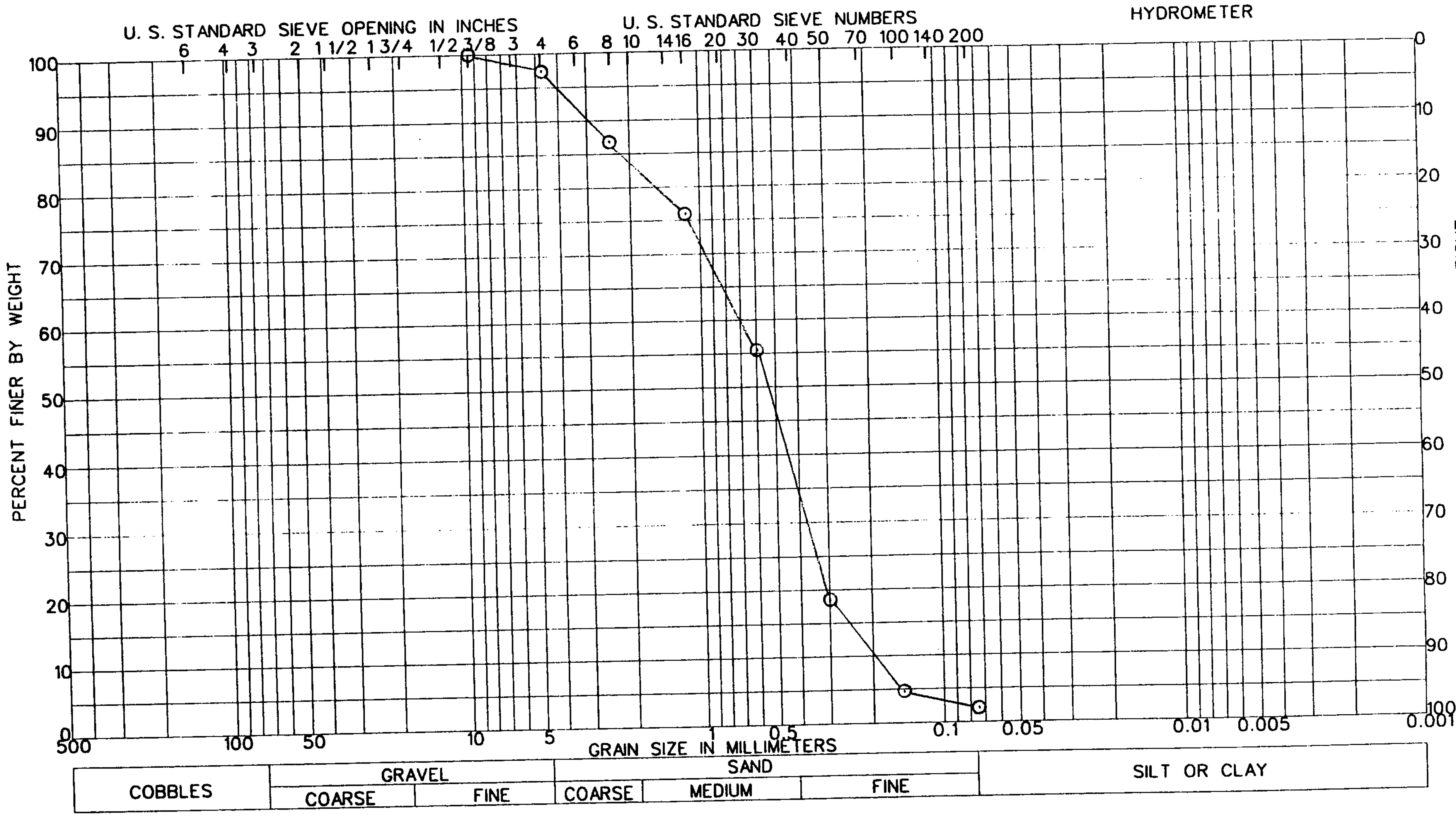

Figure A.3. Gradation for Washed Sieve Analysis of Fine Aggregate

Ā CALCULATION PROCEDURE

$$\bar{A} = [\sum(\text{Cumulative percentages passing by weight})] / 100$$

The U. S. Standard Sieves used for the Ā Calculation are:

1½ Inches

¾ Inches

⅜ Inches

#4

#8

#16

#30

#50

#100

#200

The specification for fine aggregate for developing a concrete mix design as stated in the West Virginia Department of Transportation's Standard Specifications for Roads and Bridges is that the fine aggregate Ā should be equal to 6.1 ± 0.4.

Table A.4. Mix Proportions By Batch

Batch Number	Cement Content (Bags/CY)	Cement (Pounds)	Coarse Aggregate (Pounds)	Fine Aggregate (Pounds)	Water (Pounds)	AEA (ml)
1	6	84	268	165	40.5	40
2	7.25	102	244	149	40	46
3	7.25	102	244	149	41	48
4	5	70	275	169	37	38
5	5	70	275	169	35	40
6	6	84	268	165	39.5	42
7	7.25	102	244	149	42	48
8	6	84	268	165	39.5	42
9	6	84	268	165	40	42
10	7.25	102	244	149	42	49
11	6	84	268	165	38	43
12	5	70	275	169	35	42
13	7.25	102	244	149	40.5	49
14	5	70	275	169	35.5	41
15	5	70	275	169	34.5	41

APPENDIX B:

Compressive Strength Test Results

Table B.1. Compressive Strengths in Pounds per Square Inch for Individual Cylinders
Cement Factor: Five Bags per Cubic Yard
Cylinder Size: 6" Diameter x 12" Long
One Day Old

Batch Number	4	5	12	14	15
Type of Cap					
Sulfur Mortar	1590	1520	1400	1480	1680
	1560	1500	1350	1370	1640
	1570	1520	1350	1450	1730
Steel / Neoprene	1410	1500	1340	1350	1440
	1500	1410	1340	1240	1630
	1570	1380	1200	1440	1580
Number of Specimens	6	6	6	6	6
Average Strength in psi	1533	1488	1330	1405	1617
Standard Deviation in psi	68	41	68	59	100
Coefficient of Variation in Percent	4.4	2.8	5.1	4.2	6.2

Table B.2. Compressive Strengths in Pounds per Square Inch for Individual Cylinders

Cement Factor: Five Bags per Cubic Yard

Cylinder Size: 6" Diameter x 12" Long

28 Days Old

Batch Number	4	5	12	14	15
Type of Cap					
Sulfur Mortar	4810	4600	4770	4860	4900
	4740	4530	4070	5090	4810
	4630	4720	4670	5130	4930
Steel / Neoprene	4830	4670	4830	5040	5000
	4990	4540	4760	5000	4990
	5000	4530	4850	4850	4830
Number of Specimens	6	6	6	6	6
Average Strength in psi	4833	4598	4658	4995	4910
Standard Deviation in psi	143	81	295	117	79
Coefficient of Variation in Percent	3.0	1.8	6.3	2.3	1.6

Table B.3. Compressive Strengths in Pounds per Square Inch for Individual Cylinders

Cement Factor: Six Bags per Cubic Yard

Cylinder Size: 6" Diameter x 12" Long

One Day Old

Batch Number	1	6	8	9	11
Type of Cap					
Sulfur Mortar	1630	1890	2210	2000	1750
	1560	1980	2190	2100	1810
	1560	1950	2160	2010	1930
Steel / Neoprene	1540	1800	1930	1870	1880
	1430	1980	2080	1780	1800
	1520	1870	2180	2030	1910
Number of Specimens	6	6	6	6	6
Average Strength in psi	1540	1912	2125	1965	1847
Standard Deviation in psi	65	71	106	117	71
Coefficient of Variation in Percent	4.2	3.7	5.0	6.0	3.8

Table B.4. Compressive Strengths in Pounds per Square Inch for Individual Cylinders

Cement Factor: Six Bags per Cubic Yard

Cylinder Size: 6" Diameter x 12" Long

28 Days Old

Batch Number	1	6	8	9	11
Type of Cap					
Sulfur Mortar	5160	5090	5710	5570	5660
	5090	5200	5520	5480	5340
	4950	5180	5480	5360	5460
Steel / Neoprene	5090	5310	5540	5640	5450
	5180	5360	5550	5460	5500
	4810	5380	5660	5570	5540
Number of Specimens	6	6	6	6	6
Average Strength in psi	5047	5253	5577	5513	5492
Standard Deviation in psi	141	114	89	100	106
Coefficient of Variation in Percent	2.8	2.2	1.6	1.8	1.9

Table B.5. Compressive Strengths in Pounds per Square Inch for Individual Cylinders
Cement Factor: 7.25 Bags per Cubic Yard
Cylinder Size: 6" Diameter x 12" Long
One Day Old

Batch Number	2	3	7	10	13
Type of Cap					
Sulfur Mortar	2410	2620	2560	2690	1980
	2580	2670	2460	2600	2370
	2580	2560	2550	2720	2780
Steel / Neoprene	2320	2410	2530	2740	2740
	2350	2600	2390	2810	2690
	2350	2670	2300	2690	2760
Number of Specimens	6	6	6	6	6
Average Strength in psi	2432	2588	2465	2708	2553
Standard Deviation in psi	119	97	103	69	319
Coefficient of Variation in Percent	4.9	3.7	4.2	2.6	12.5

Table B.6. Compressive Strengths in Pounds per Square Inch for Individual Cylinders
Cement Factor: 7.25 Bags per Cubic Yard
Cylinder Size: 6" Diameter x 12" Long
28 Days Old

Batch Number	2	3	7	10	13
Type of Cap					
Sulfur Mortar	5760	5450	5620	6380	6300
	5690	5500	5610	6560	6210
	5730	5590	5760	6310	6310
Steel / Neoprene	5910	5390	5730	6540	6220
	5840	5480	5760	6350	6380
	5570	5460	5750	6470	6440
Number of Specimens	6	6	6	6	6
Average Strength in psi	5750	5478	5705	6435	6310
Standard Deviation in psi	118	66	71	104	89
Coefficient of Variation in Percent	2.1	1.2	1.2	1.6	1.4

Table B.7. Compressive Strengths in Pounds per Square Inch for Individual Cylinders
Cement Factor: Five Bags per Cubic Yard
Cylinder Size: 4" Diameter x 8" Long
One Day Old

Batch Number	4	5	12	14	15
Type of Cap					
Sulfur Mortar	1430	1380	1150	1320	1480
	1440	1500	1150	1360	1540
	1400	1390	1150	1330	1420
Steel / Neoprene	1360	1370	1070	1290	1350
	1430	1350	1030	1280	1460
	1440	1390	980	1220	1370
Number of Specimens	6	6	6	6	6
Average Strength in psi	1417	1397	1088	1300	1437
Standard Deviation in psi	31	53	73	49	71
Coefficient of Variation in Percent	2.2	3.8	6.7	3.7	5.0

Table B.8. Compressive Strengths in Pounds per Square Inch for Individual Cylinders

Cement Factor: Five Bags per Cubic Yard

Cylinder Size: 4" Diameter x 8" Long

28 Days Old

Batch Number	4	5	12	14	15
Type of Cap					
Sulfur Mortar	5170	4770	4890	5210	5090
	5290	4700	4700	5250	5130
	5130	4770	4770	5250	5210
Steel / Neoprene	5170	4620	4700	5250	5090
	5010	4770	4660	4930	5050
	5130	4660	4620	4970	5250
Number of Specimens	6	6	6	6	6
Average Strength in psi	5150	4715	4723	5143	5137
Standard Deviation in psi	90	65	96	151	78
Coefficient of Variation in Percent	1.8	1.4	2.0	2.9	1.5

Table B.9. Compressive Strengths in Pounds per Square Inch for Individual Cylinders

Cement Factor: Six Bags per Cubic Yard

Cylinder Size: 4" Diameter x 8" Long

One Day Old

Batch Number	1	6	8	9	11
Type of Cap					
Sulfur Mortar	1400	1910	1850	1880	1710
	1580	1770	1880	1930	1700
	1590	1880	1980	1890	1770
Steel / Neoprene	1520	1680	1740	1610	1640
	1460	1740	1760	1690	1760
	1500	1810	1660	1840	1620
Number of Specimens	6	6	6	6	6
Average Strength in psi	1508	1798	1812	1807	1700
Standard Deviation in psi	72	87	114	127	61
Coefficient of Variation in Percent	4.8	4.8	6.3	7.0	3.6

Table B.10. Compressive Strengths in Pounds per Square Inch for Individual Cylinders

Cement Factor: Six Bags per Cubic Yard

Cylinder Size: 4" Diameter x 8" Long

28 Days Old

Batch Number	1	6	8	9	11
Type of Cap					
Sulfur Mortar	5250	5810	6210	6090	6290
	5410	5770	6010	5970	6250
	5250	5170	5970	5250	5970
Steel / Neoprene	5570	5570	5890	5890	5930
	5530	5730	6090	6090	6010
	5730	5810	6090	5770	5850
Number of Specimens	6	6	6	6	6
Average Strength in psi	5457	5643	6042	5843	6050
Standard Deviation in psi	190	248	112	315	179
Coefficient of Variation in Percent	3.5	4.4	1.9	5.4	3.0

Table B.11. Compressive Strengths in Pounds per Square Inch for Individual Cylinders

Cement Factor: 7.25 Bags per Cubic Yard

Cylinder Size: 4" Diameter x 8" Long

One Day Old

Batch Number	2	3	7	10	13
Type of Cap					
Sulfur Mortar	2320	2470	2350	2530	2590
	2330	2350	2300	2520	2430
	2210	2450	2320	2590	2670
Steel / Neoprene	2190	2380	2280	2600	2520
	2310	2440	2180	2590	2640
	2460	2440	2230	2510	2540
Number of Specimens	6	6	6	6	6
Average Strength in psi	2303	2422	2277	2557	2565
Standard Deviation in psi	97	46	62	41	87
Coefficient of Variation in Percent	4.2	1.9	2.7	1.6	3.4

Table B.12. Compressive Strengths in Pounds per Square Inch for Individual Cylinders

Cement Factor: 7.25 Bags per Cubic Yard

Cylinder Size: 4" Diameter x 8" Long

28 Days Old

Batch Number	2	3	7	10	13
Type of Cap					
Sulfur Mortar	6170	4770	6330	6800	6490
	6170	5770	6570	6840	7160
	6450	5930	6370	6720	5930
Steel / Neoprene	5970	5890	6330	6880	7120
	6010	5850	6210	6720	6640
	6090	6050	6370	7000	6680
Number of Specimens	6	6	6	6	6
Average Strength in psi	6143	5710	6363	6828	6670
Standard Deviation in psi	171	470	117	104	452
Coefficient of Variation in Percent	2.8	8.2	1.8	1.5	6.8

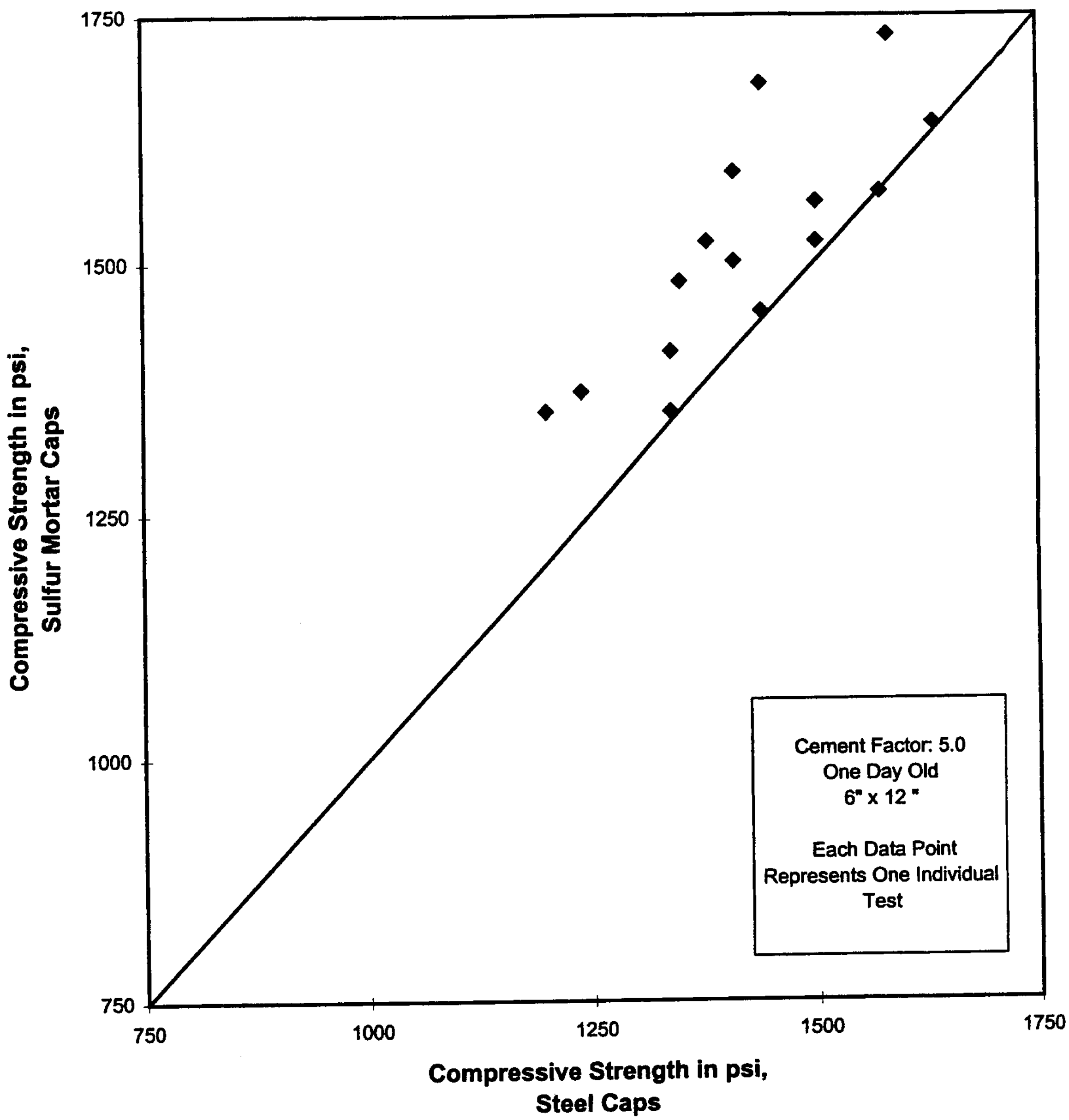

Figure B.1. Compressive Strength of Concrete Cylinders Using Different Capping Media

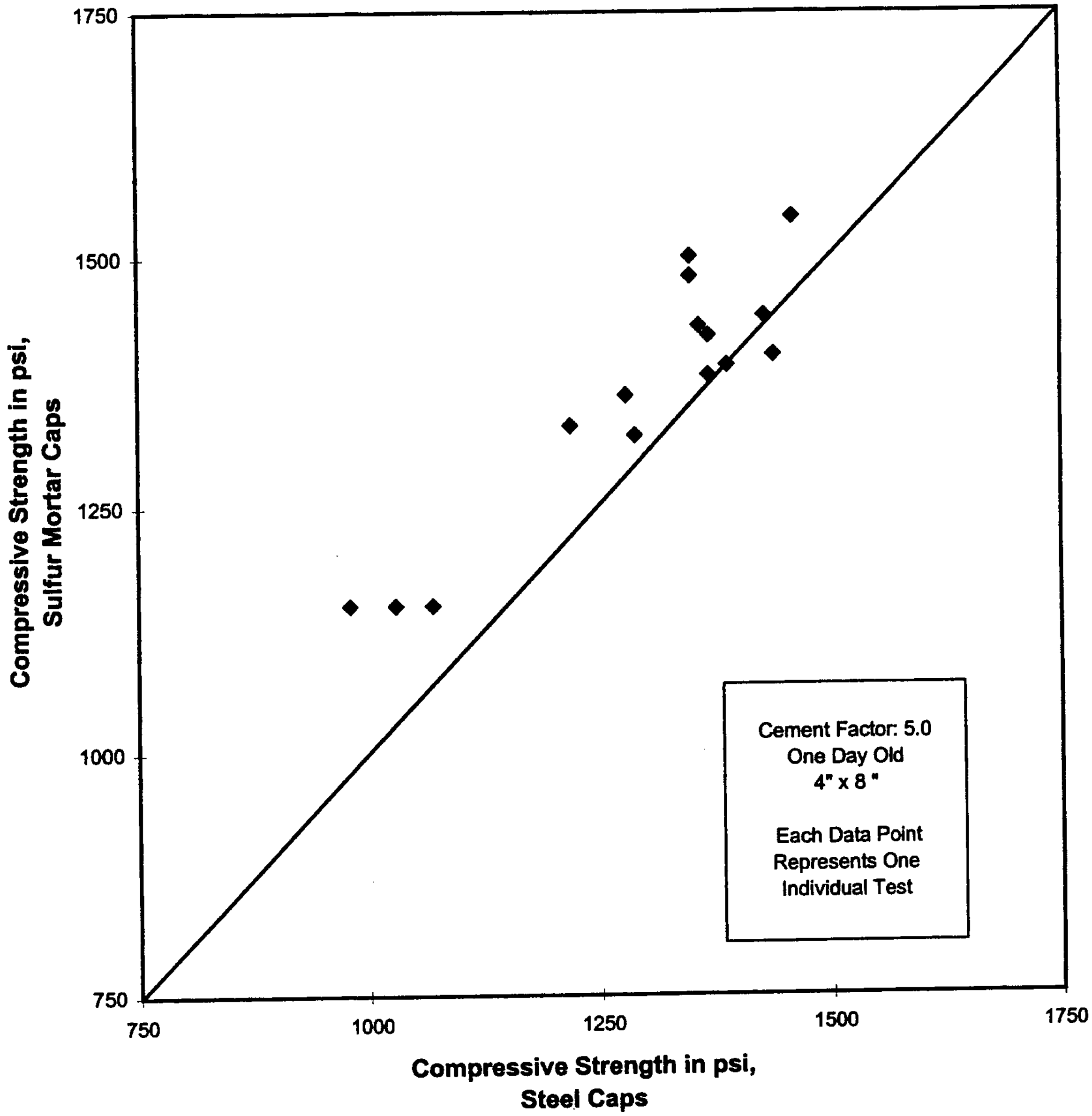

Figure B.2. Compressive Strength of Concrete Cylinders Using Different Capping Media

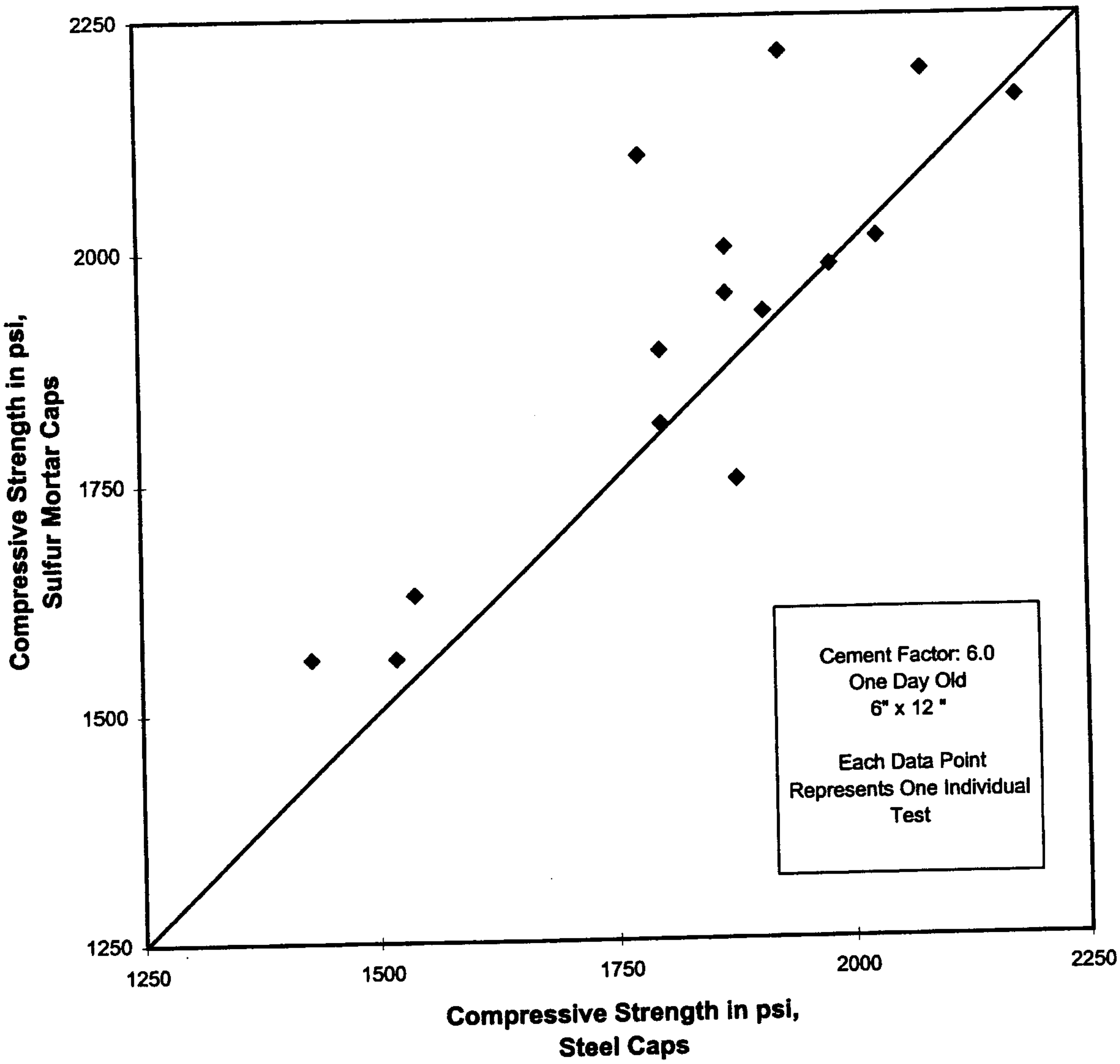

Figure B.3. Compressive Strength of Concrete Cylinders Using Different Capping Media, psi

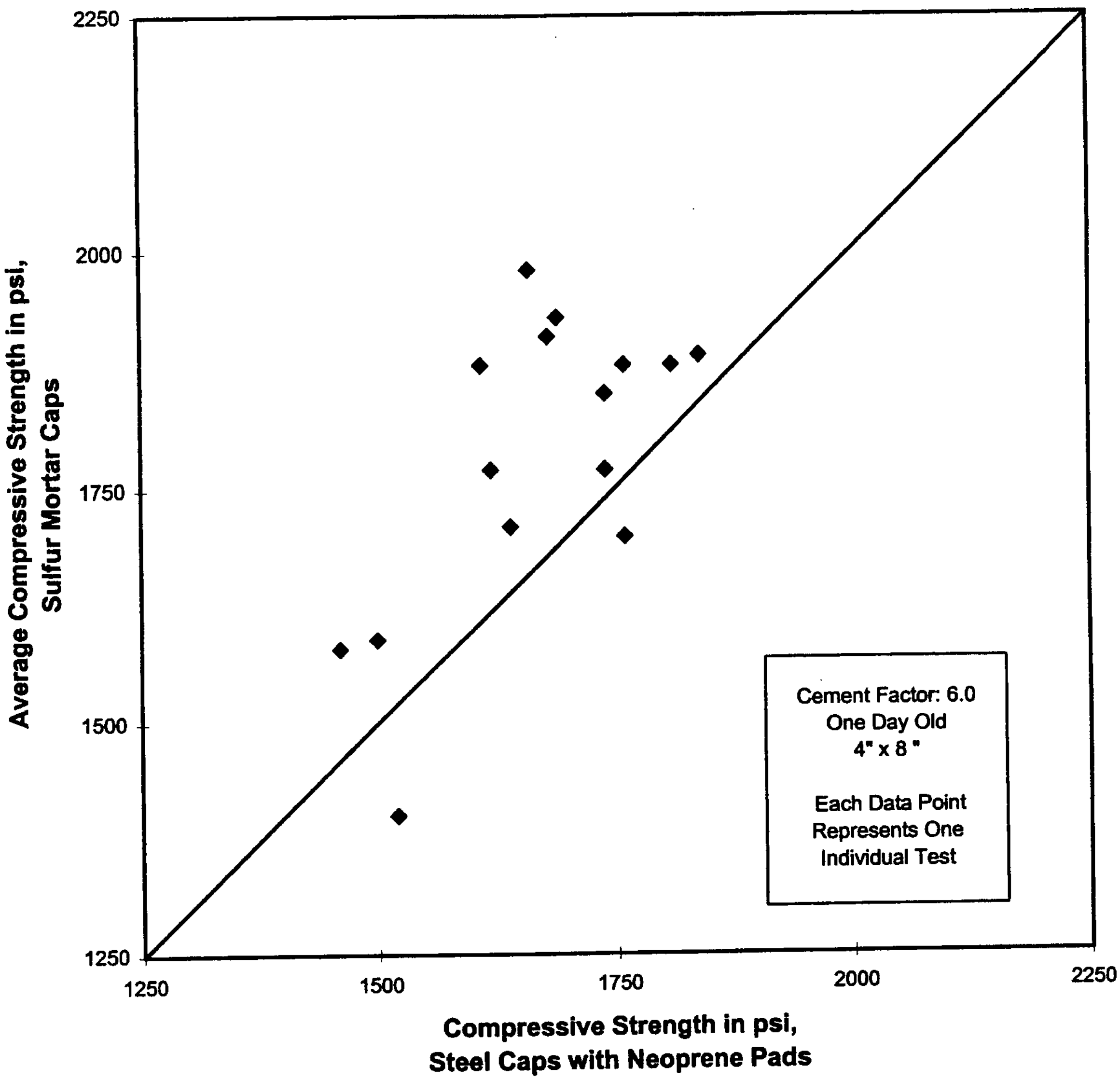

Figure B.4. Compressive Strength of Concrete Cylinders Using Different Capping Media

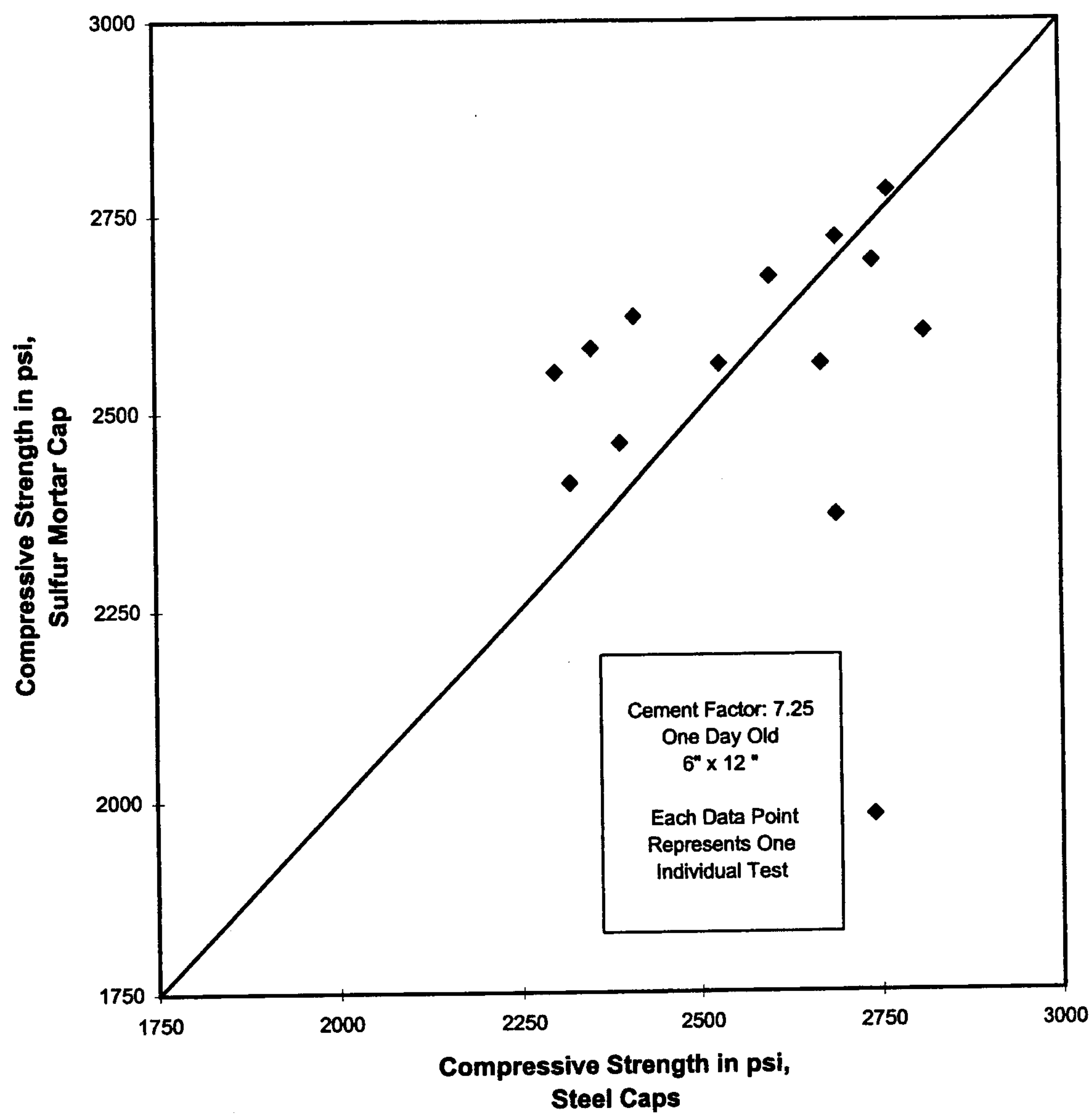

Figure B.5. Compressive Strength of Concrete Cylinders Using Different Capping Media

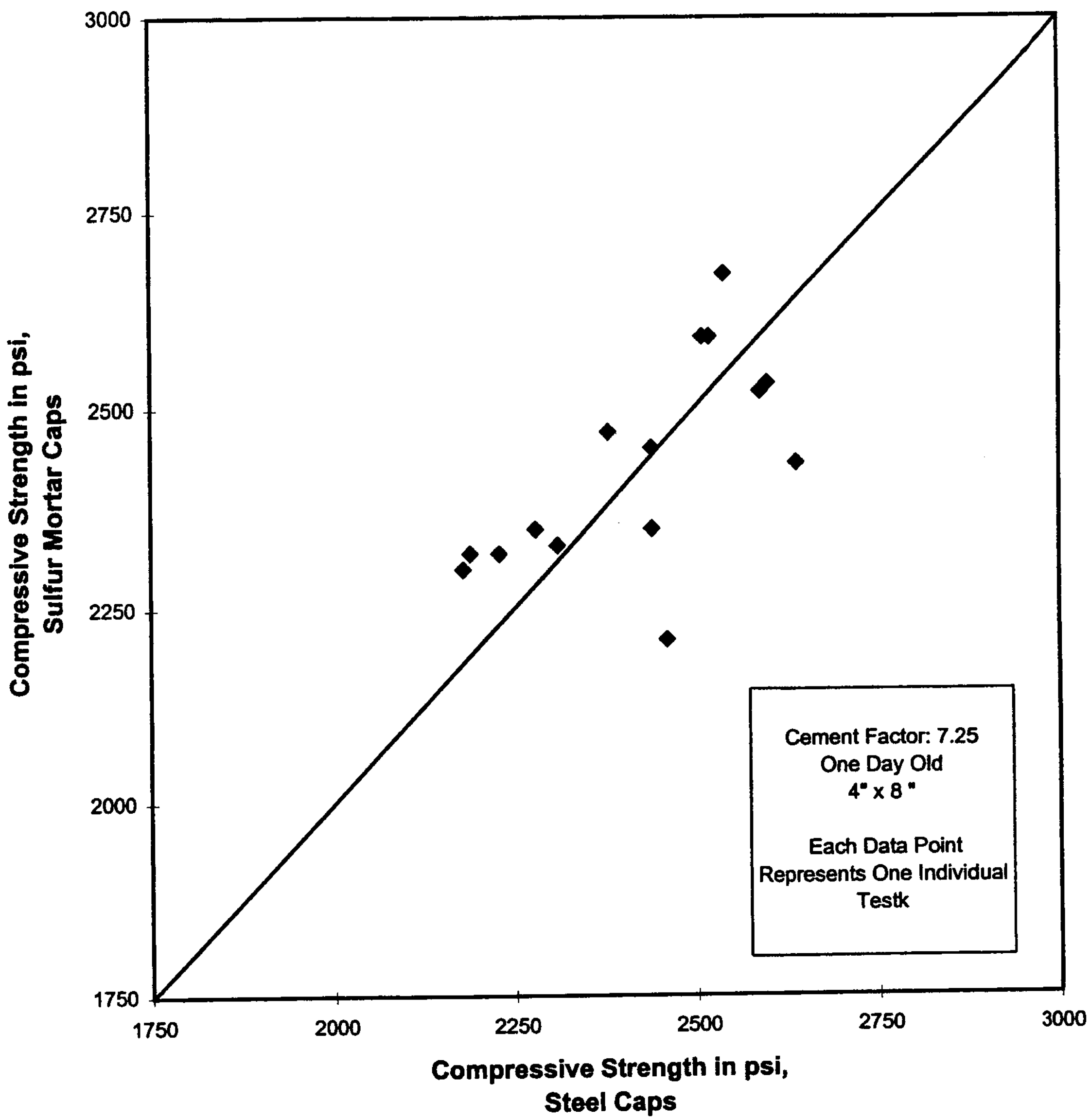

Figure B.6. Compressivestrength of Concrete Cylinders Using Different Capping Media

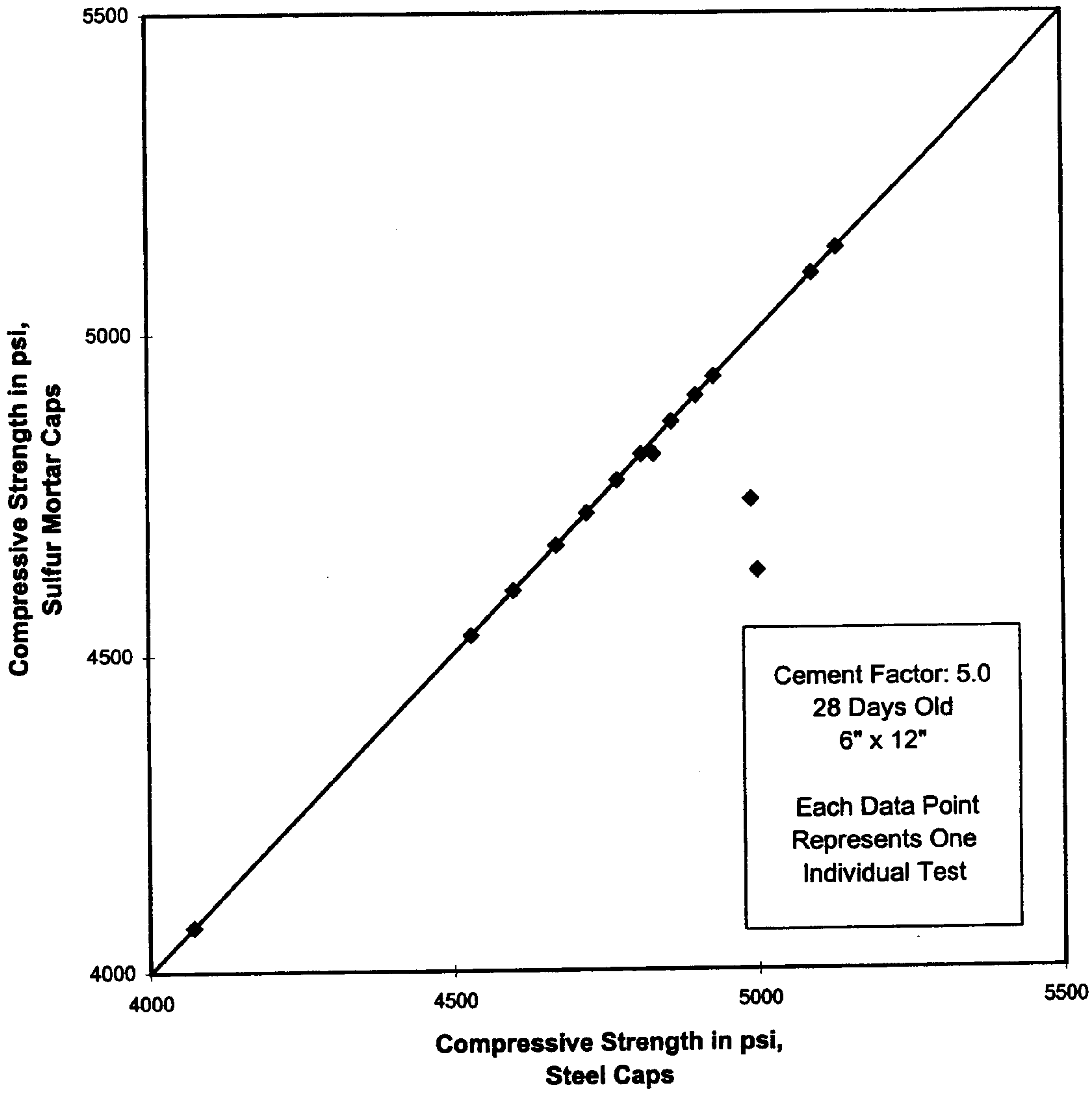

Figure B.7. Compressive Strength of Concrete Cylinders Using Different Capping Media

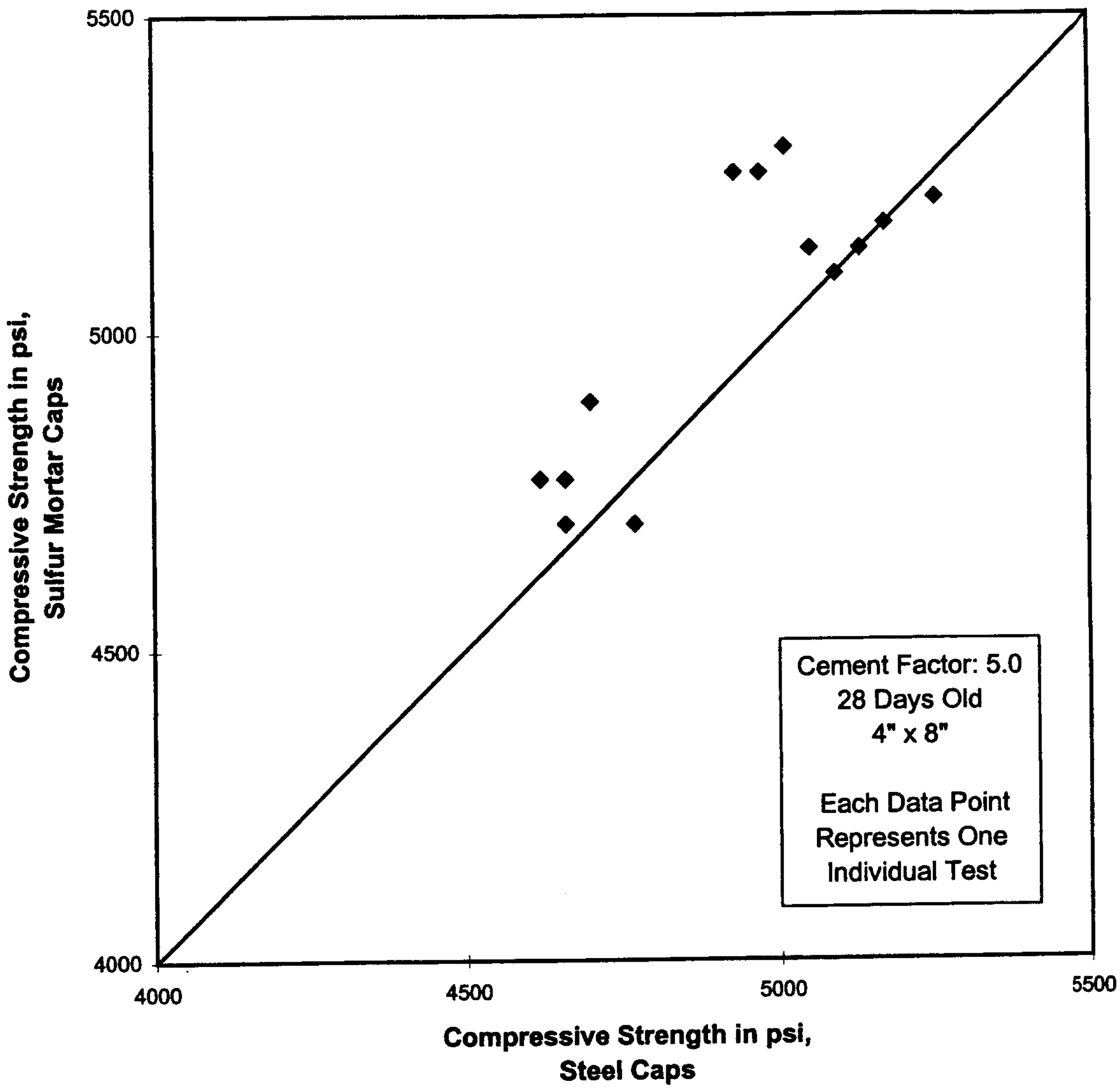

Figure B.8. Compressive Strength of Concrete Cylinders Using Different Capping Media

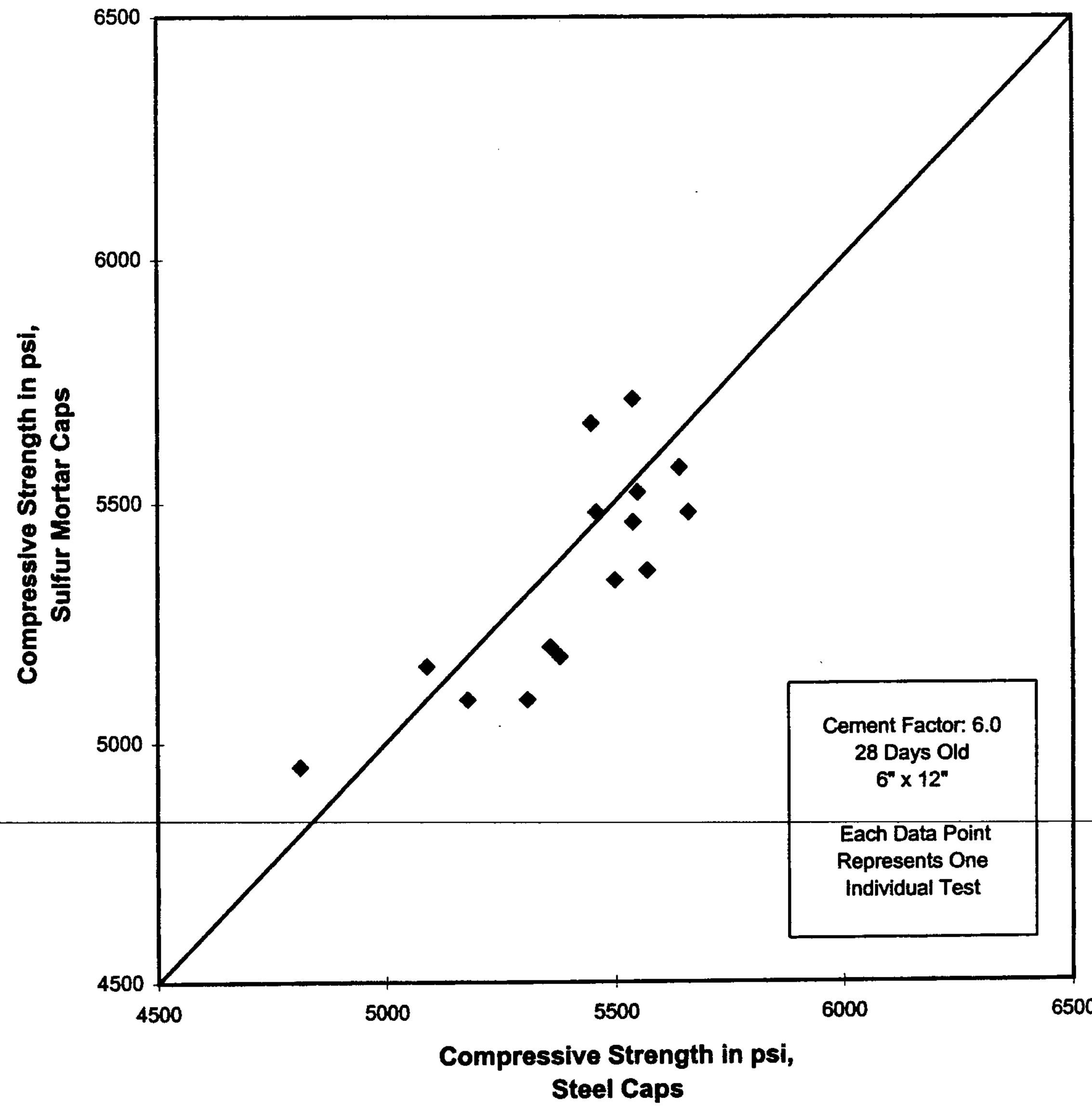

Figure B.9. Compressive Strength of Concrete Cylinders Using Different Capping Media

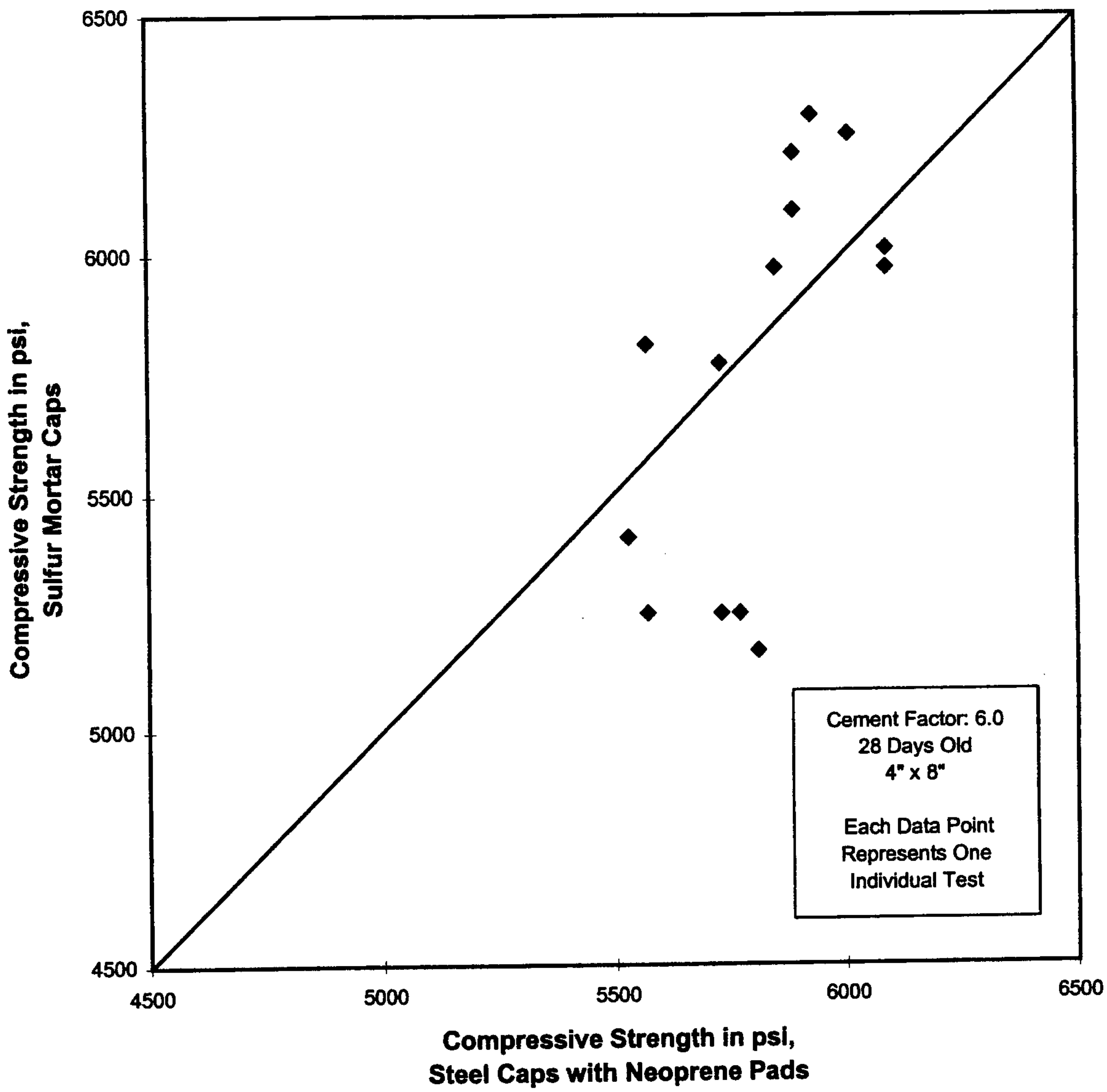

Figure B.10. Compressive Strength of Concrete Cylinders Using Different Capping Media

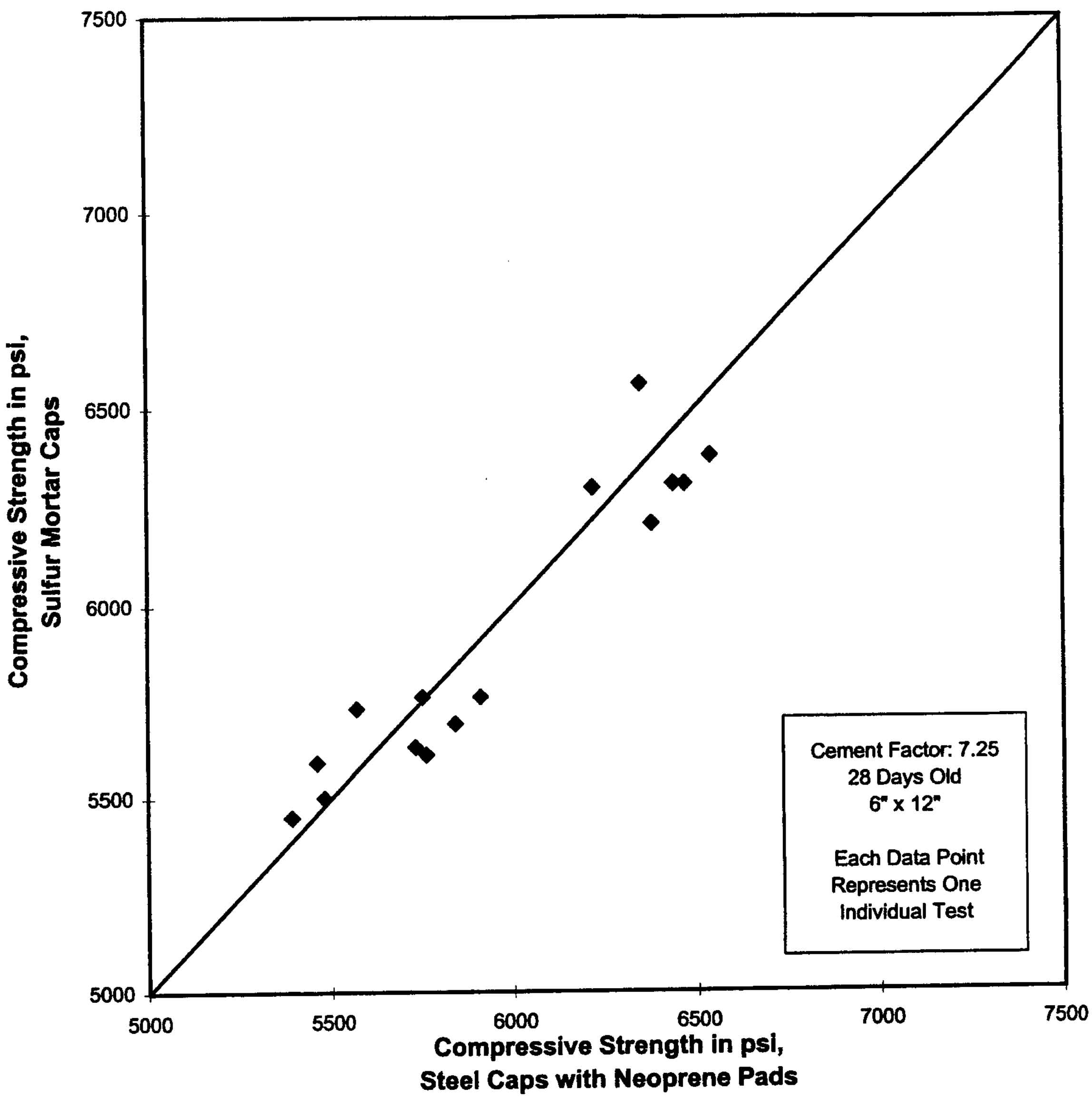

Figure B.11. Compressive Strength of Concrete Cylinders Using Different Capping Media

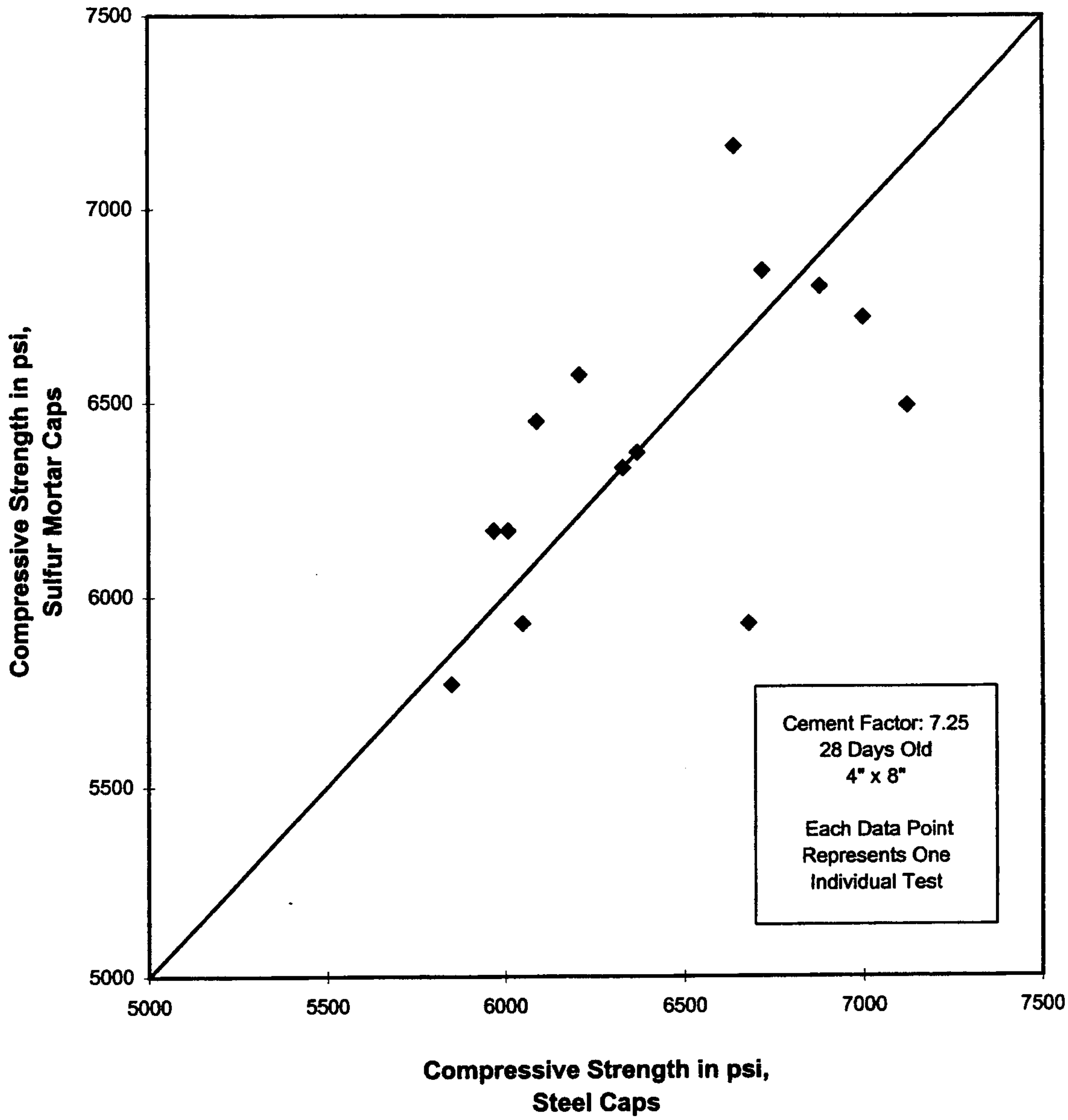

Figure B.12. Compressive Strength of Concrete Cylinders Using Different Capping Media

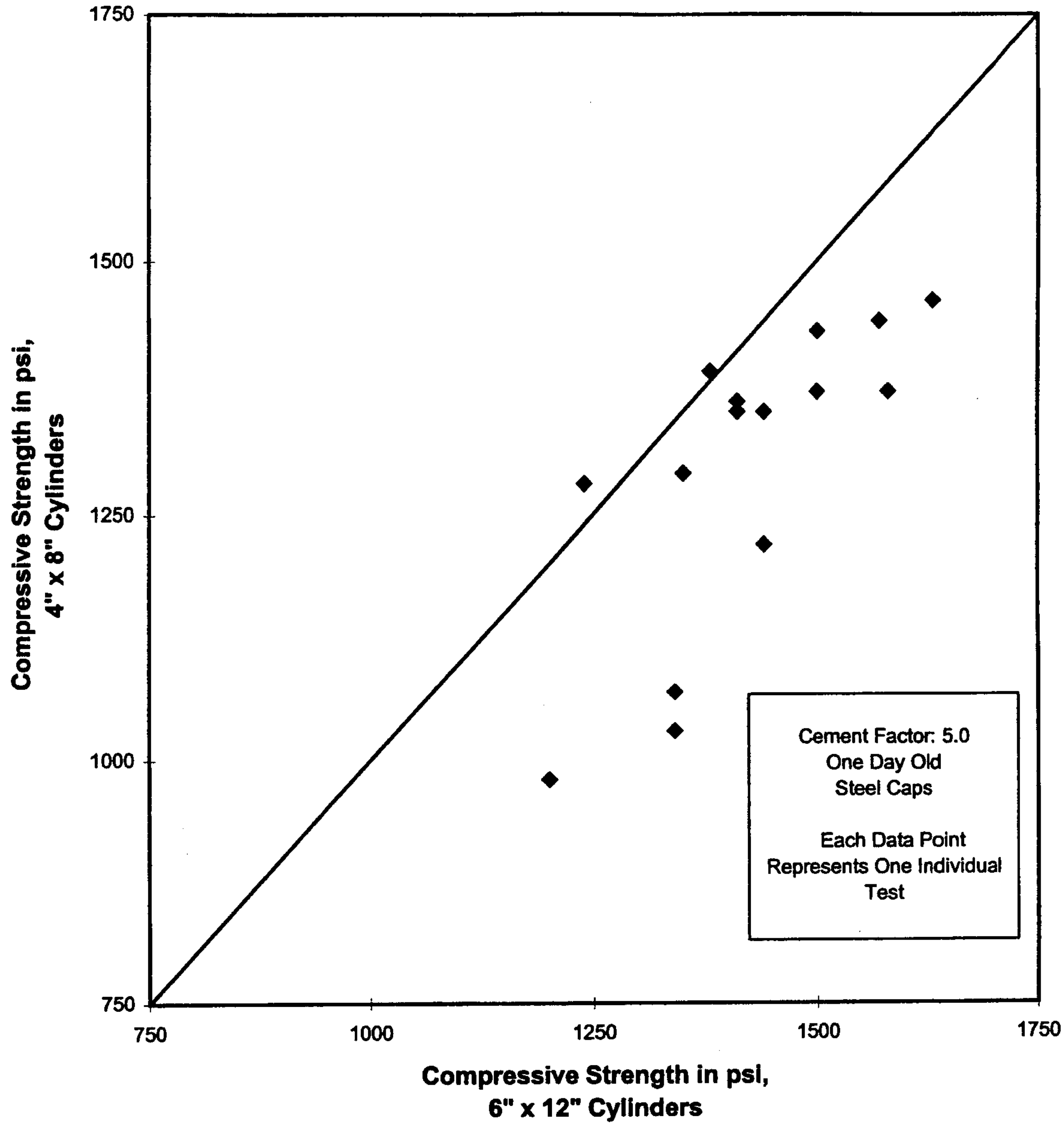

Figure B.13. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

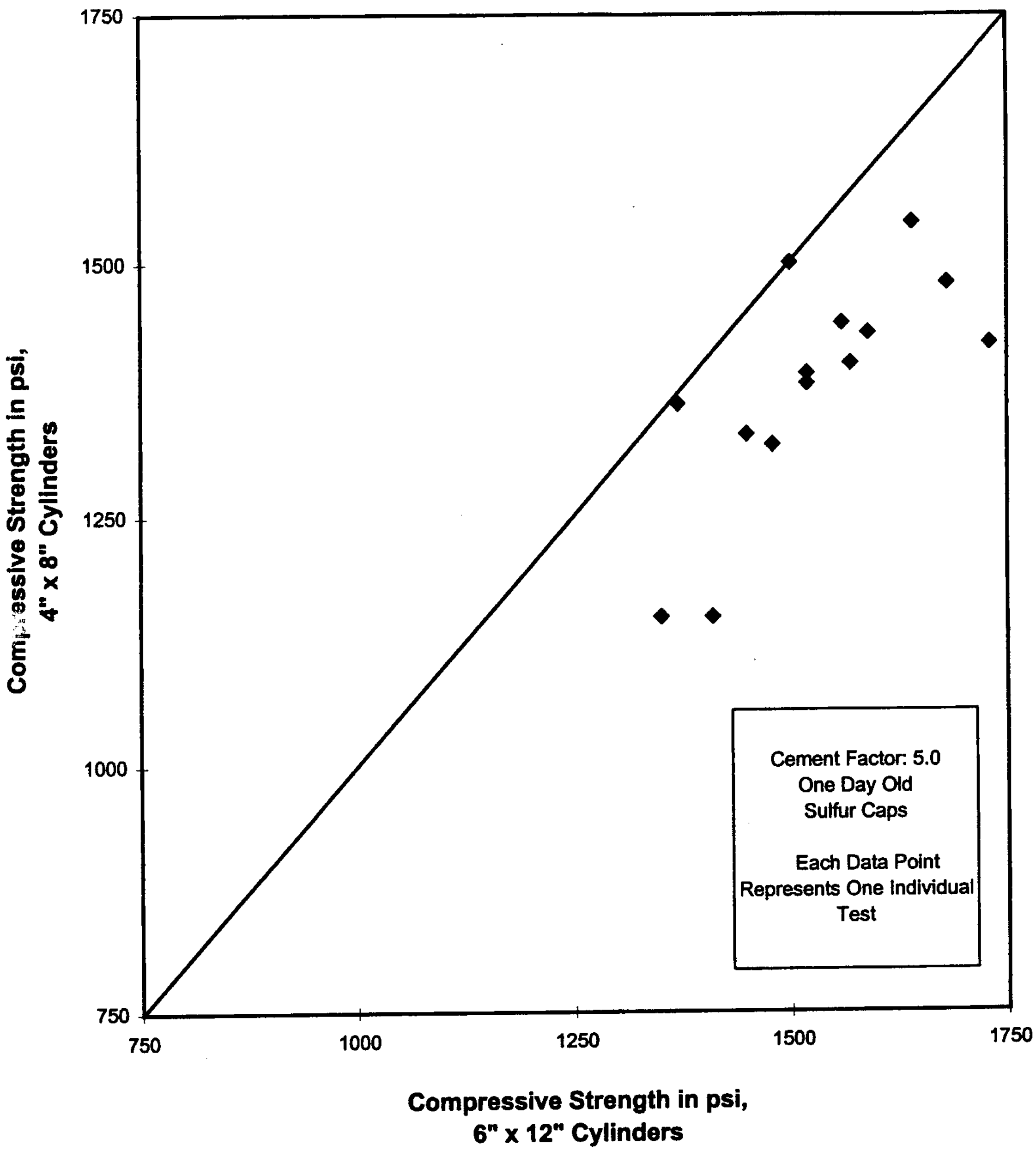

Figure B.14. Compressive Strength of 4" x8" vs. 6" x 12" Concrete Cylinders

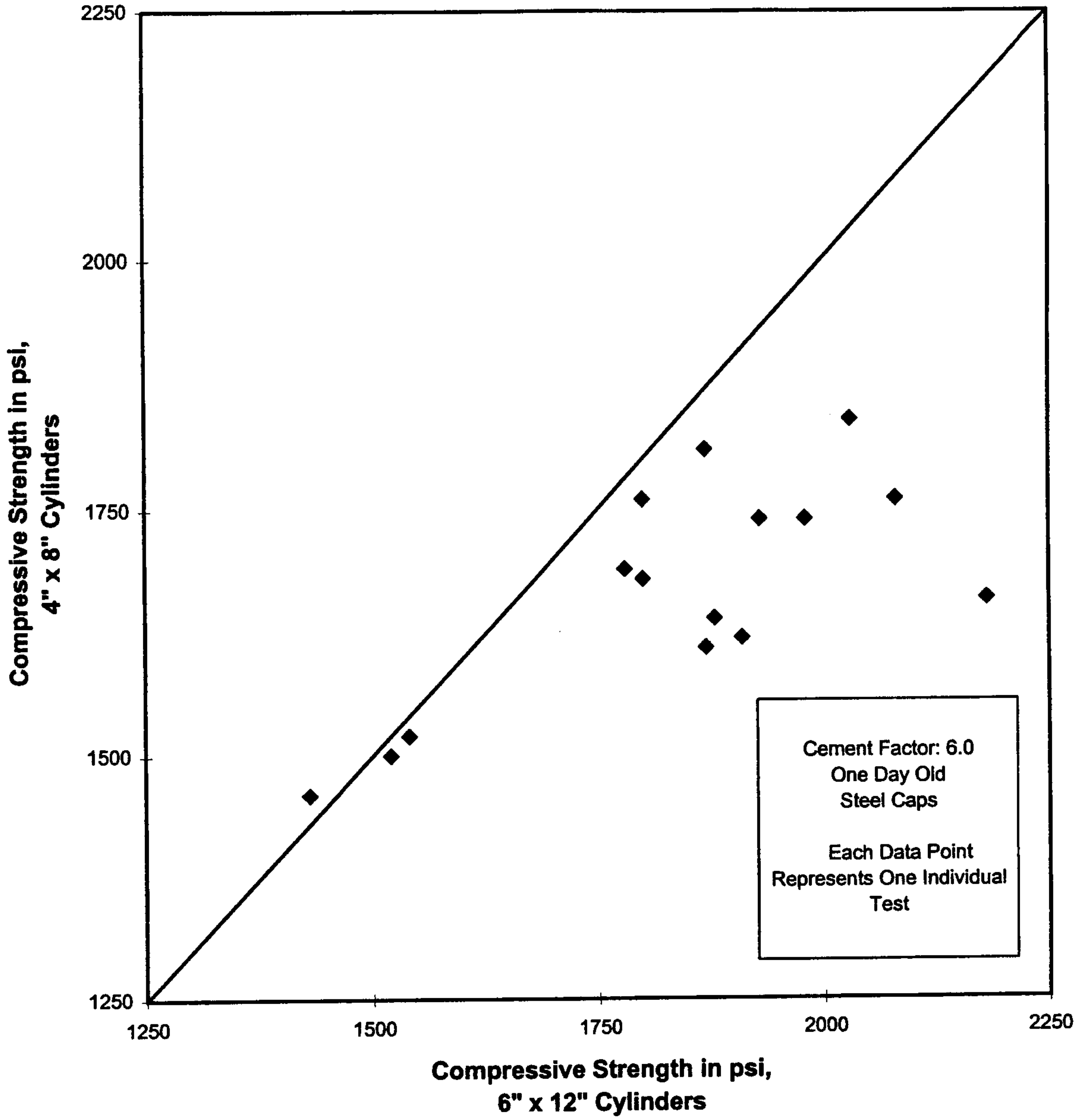

Figure B.15. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

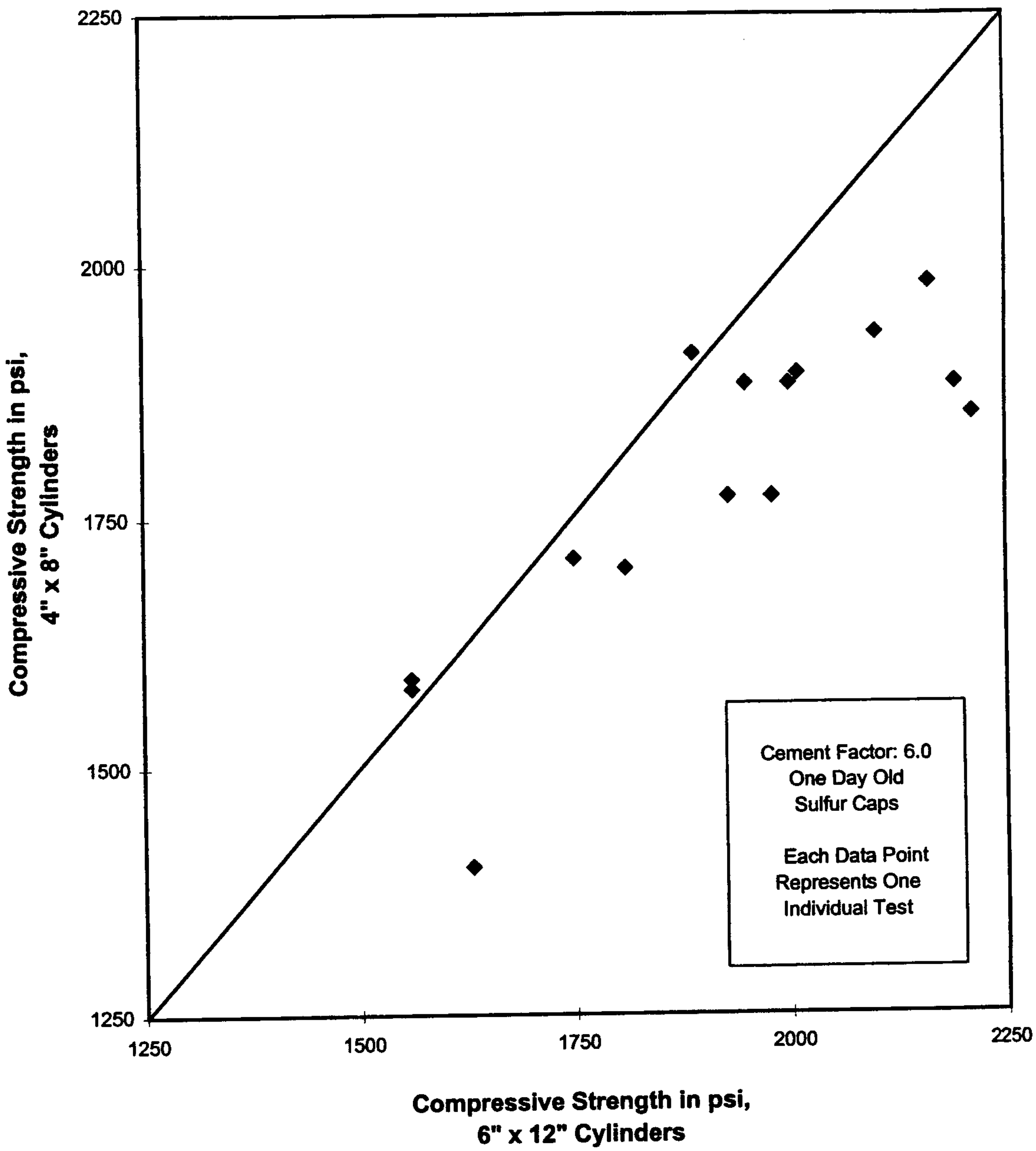

Figure B.16. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

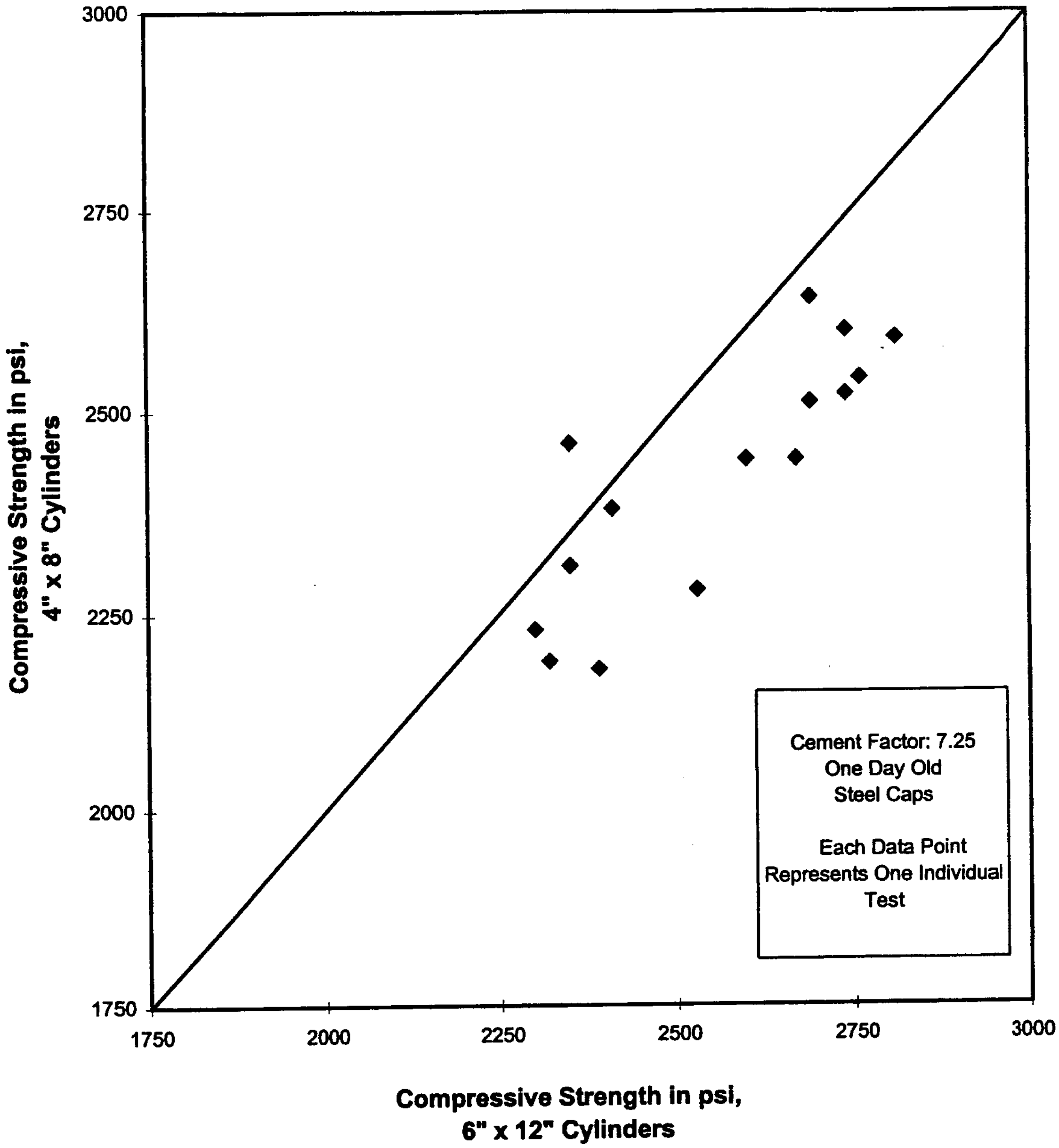

Figure B.17. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

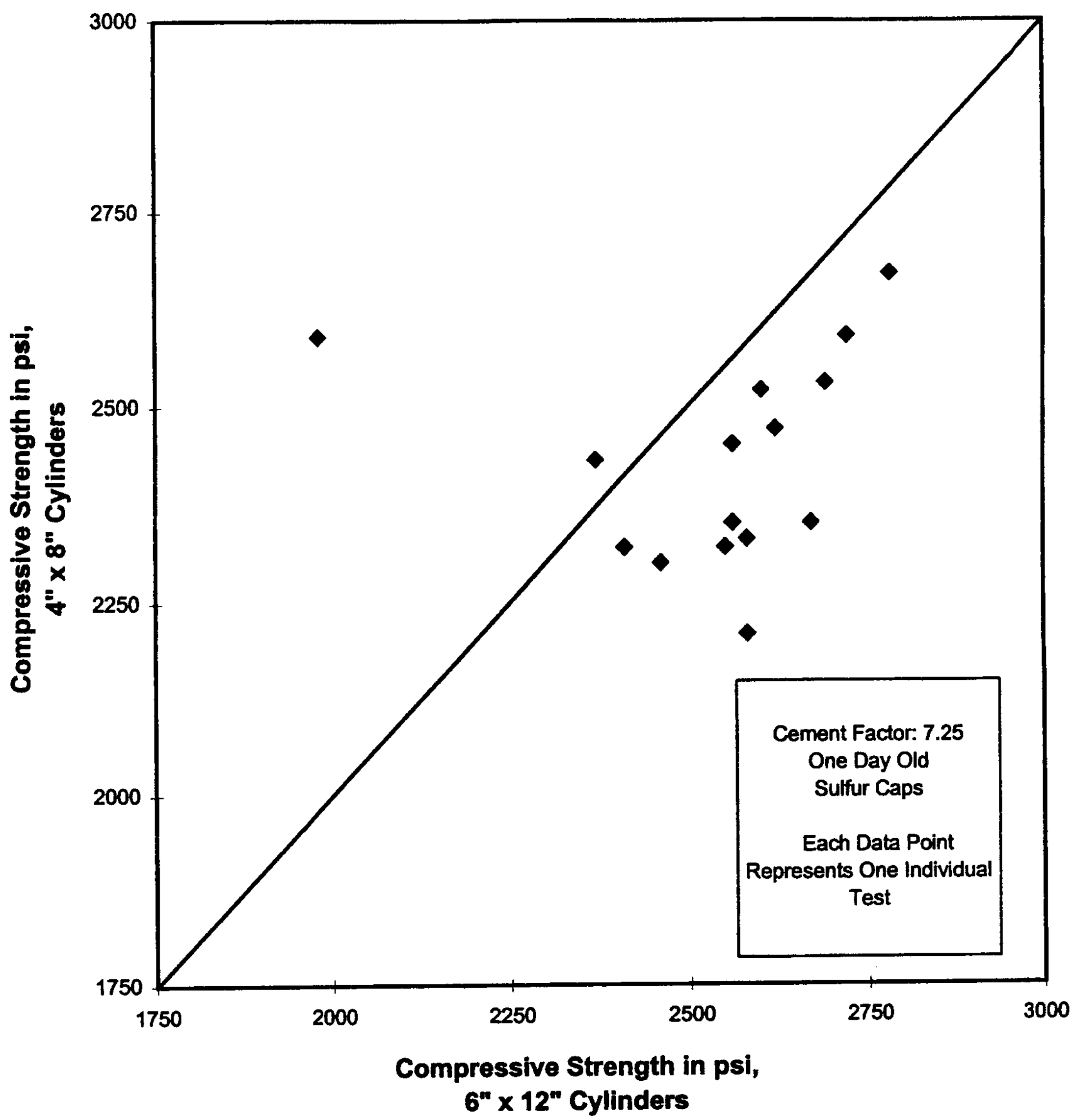

Figure B.18. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

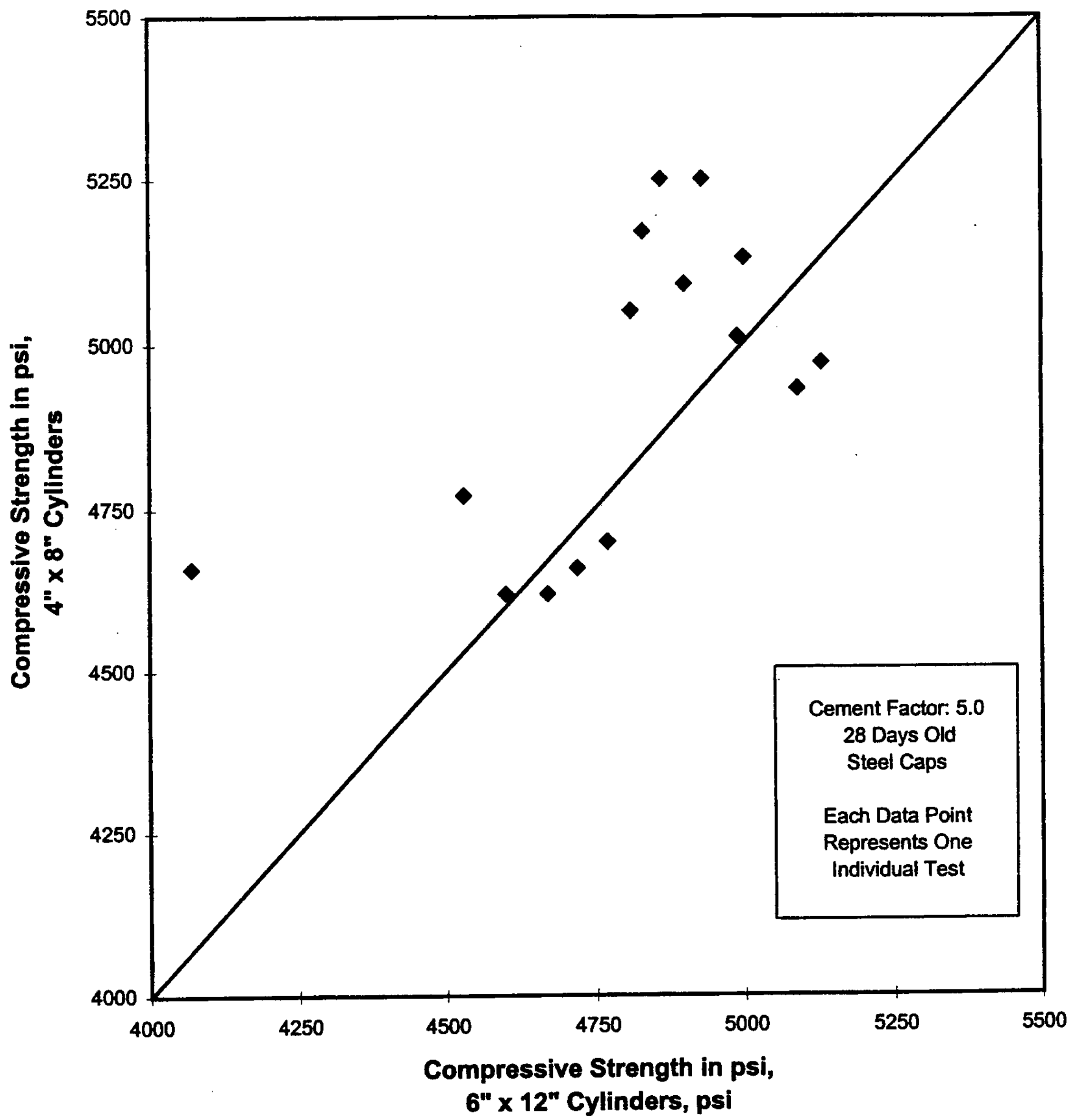

Figure B.19. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

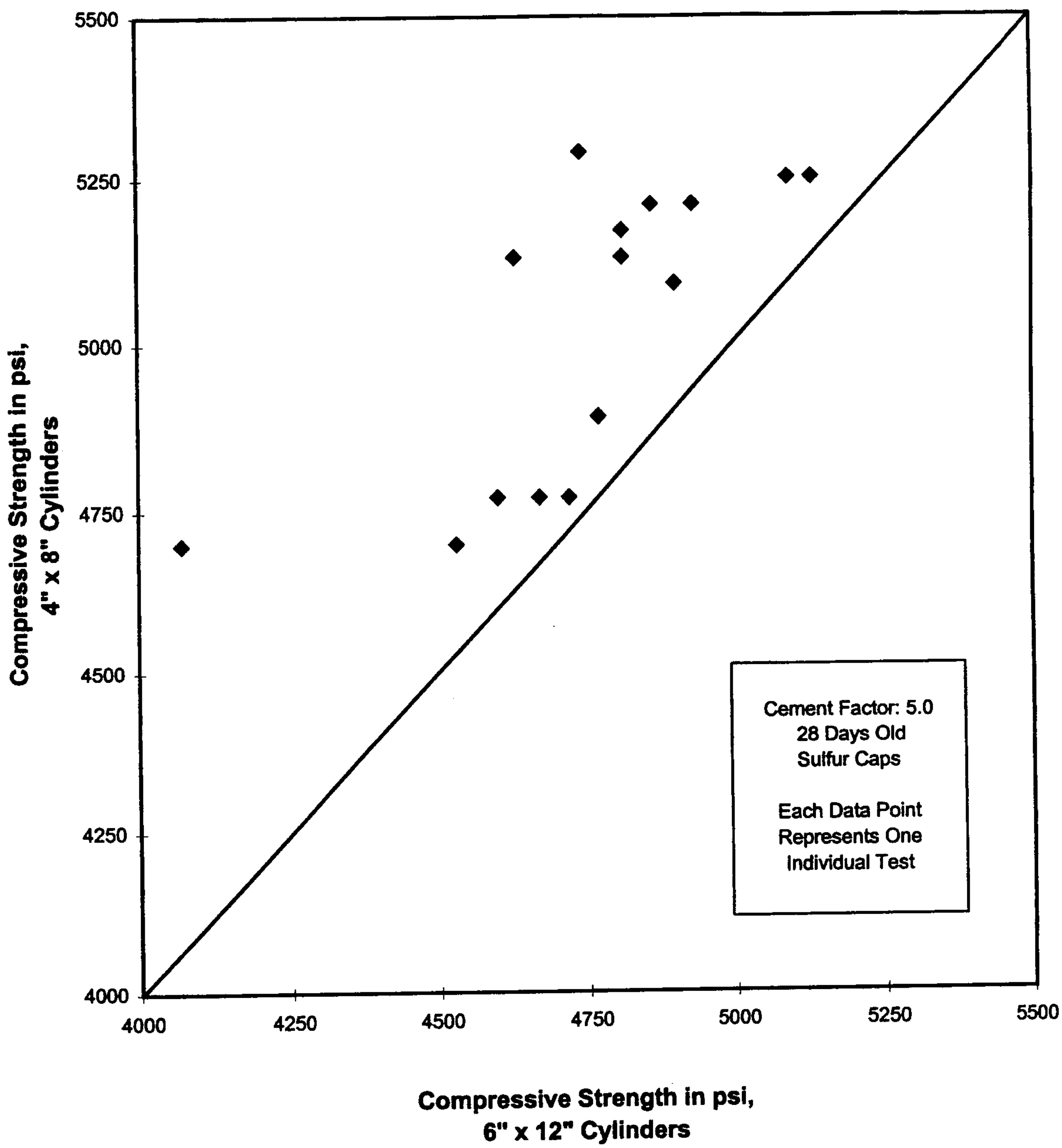

Figure B.20. Compressive Strength of 4" x 8" vs. 6" x 12 Concrete Cylinders

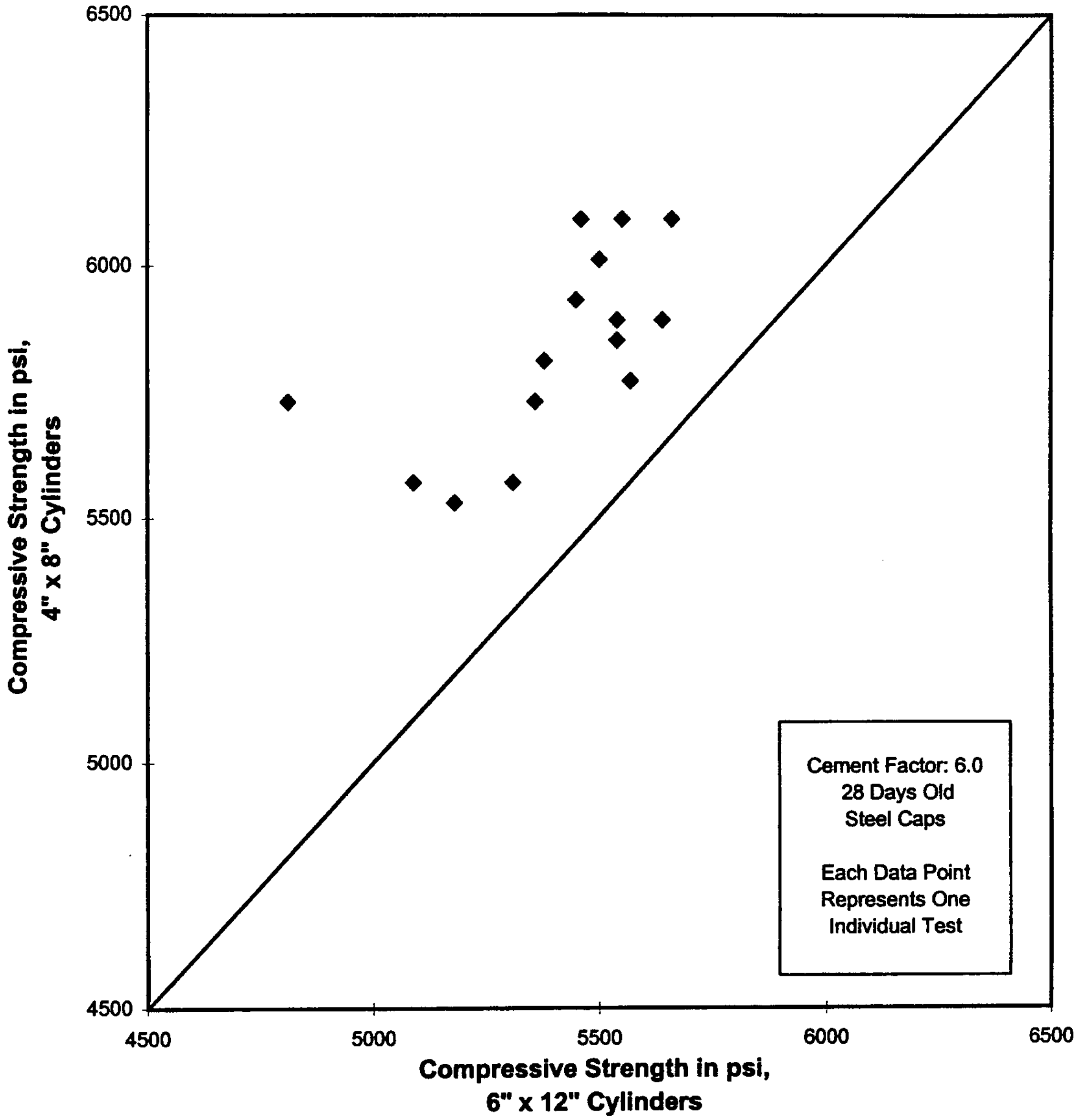

Figure B.21. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

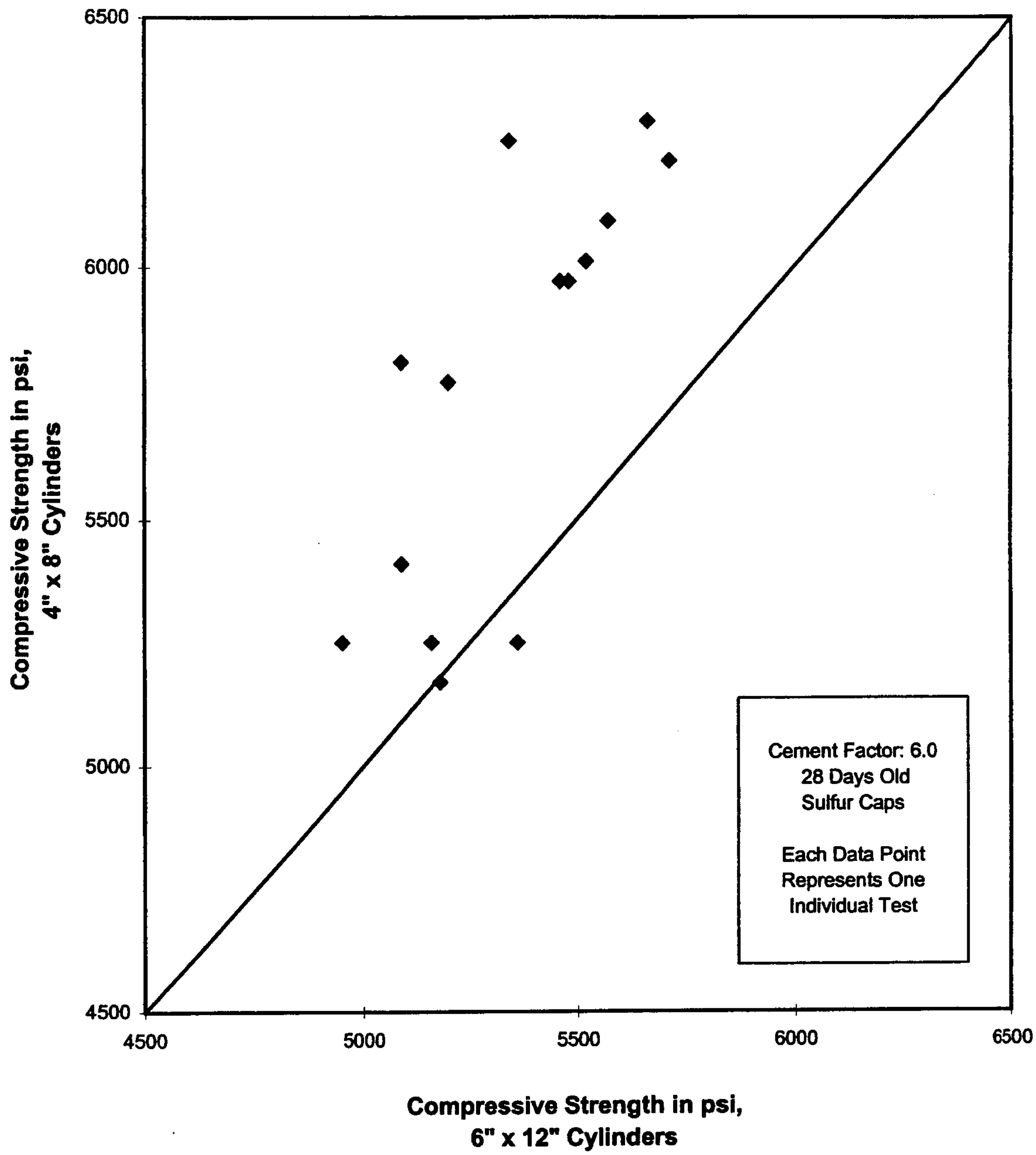

Figure B.22. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

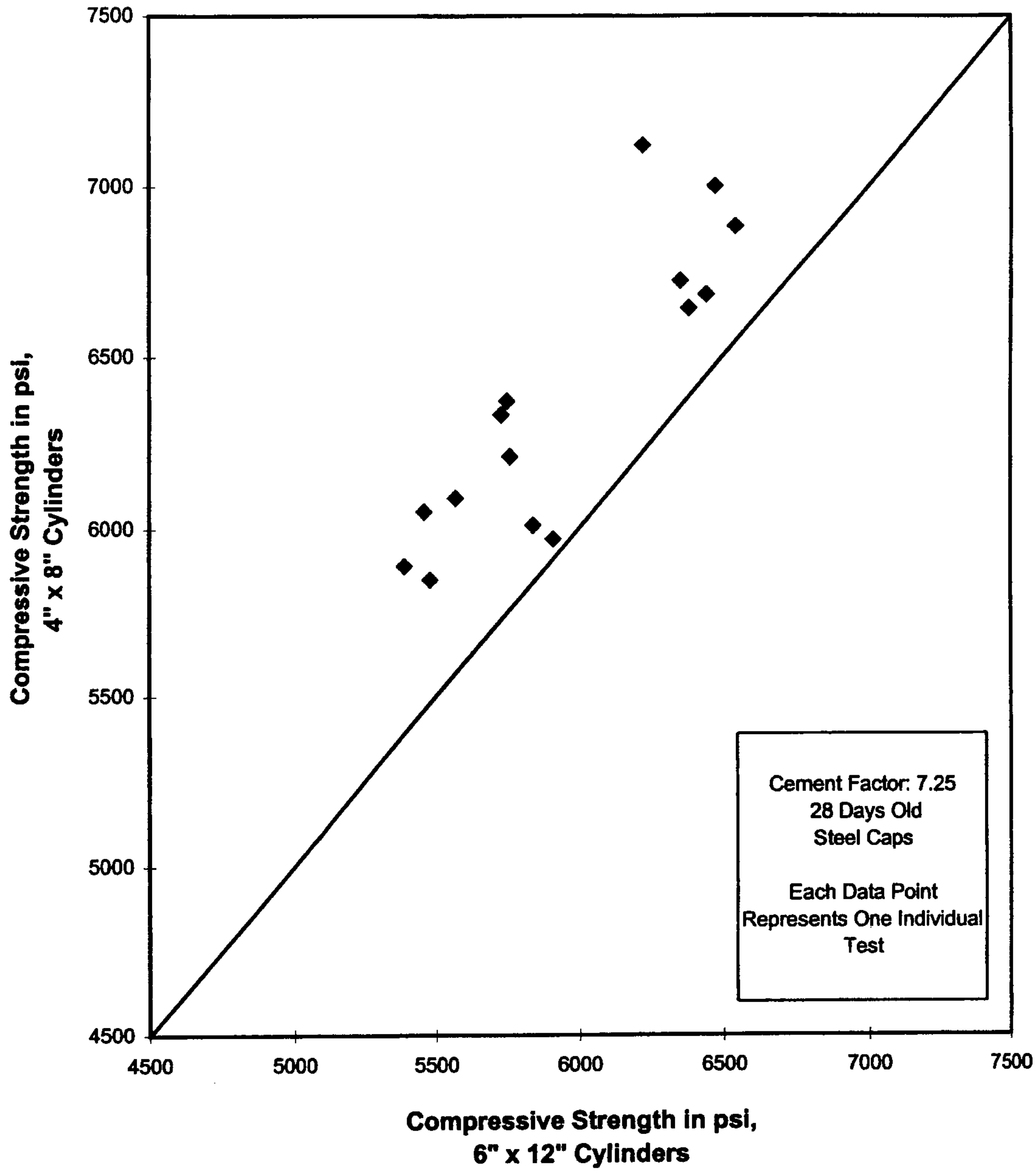

Figure B.23. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

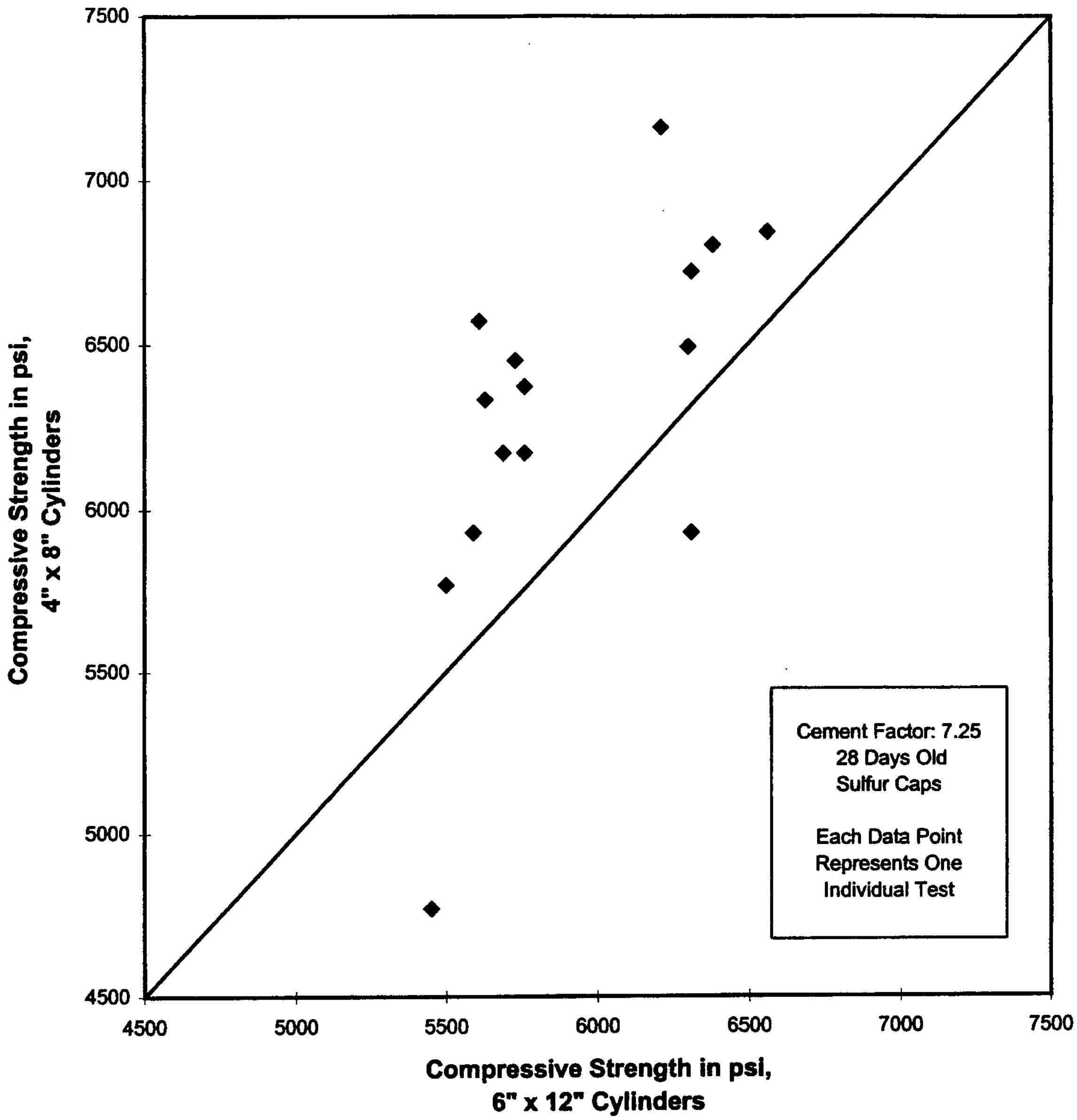

Figure B.24. Compressive Strength of 4" x 8" vs. 6" x 12" Concrete Cylinders

APPENDIX C:

Data for Analysis of Variance

Table C.1. Data for Analysis of Variance

Source of Variation	Sum of Squares	d.o.f.	Mean Squares	F Value	Pr > F	Significant? (Alpha=.05)
Curing Time (CT)	398,307,422	1	398,307,422	6,376.91	.0000	Yes
Cement Factor (CF)	27,417,732	2	13,708,866	219.48	.0000	Yes
Dimensions (Dim)	293,337	1	293,337	4.70	.0327	Yes
Capping (Cap)	2,567	1	2,567	0.04	.8398	No
CT*CF	457,537	2	228,769	3.66	.0293	Yes
CT*Dim	1,706,229	1	1,706,229	27.32	.0000	Yes
CT*Cap	68,211	1	68,211	1.09	.2986	No
CF*Dim	99,865	2	49,932	0.80	.4526	No
CF*Cap	28,563	2	14,282	0.23	.7960	No
Dim*Cap	5,866	1	5,866	0.09	.7599	No
CT*CF*Dim	98,819	2	49,410	0.79	.4563	No
CT*CF*Cap	10,835	2	5,418	0.09	.9170	No
CT*Dim*Cap	1,725	1	1,725	0.03	.8684	No
CF*Dim*Cap	13,918	2	6,959	0.11	.8947	No
CT*CF*Dim*Cap	32,217	2	16,109	0.26	.7732	No
Error	5,996,247	96	62,461			
Total	434,541,090	119				